EGERTON UNIVERSITY

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15TH BIENNIAL INTERNATIONAL CONFERENCE

CONFERENCE PROCEEDINGS

THEME

Research for Innovative Solutions in the 21st Century

MARCH 19-21

2024

SPONSORED BY:

"Transforming Lives through Quality Education"

15TH BIENNIAL INTERNATIONAL CONFERENCE

THEME:

RESEARCH FOR INNOVATIVE SOLUTIONS IN THE 21ST CENTURY

Physical and Virtual

19th – 21st MARCH, 2024

ARC (AGRICULTURE RESOURCE CENTRE) HOTEL,
EGERTON UNIVERSITY,
NJORO, KENYA

Message from

Director Research and Extension

Prof. George Owuor

Director (Research & Extension)

Egerton University held its Biennial International Conference on the 19th, 20th and 21st March 2024. This was the 15th edition of the International Conference organized by the University and brought together people from academia, research institutions and other industry experts from various fields to a common forum. The Conference was organized and hosted by the Directorate of Research and Extension and it attracted over 500 participants. The aim of the conference was to provide a platform for participants to share their experiences and research results, deliberate and exchange innovative cutting-edge development ideas, concepts and actions. The presentations included keynote addresses, paper presentations, interactive panel discussions, question and answer sessions and exhibitions. The conference was blended (virtual and face-to-face sessions). The theme of the conference was **Research for Innovative Solutions in the 21st Centur**y. In a highly volatile and uncertain times, organizations need to be resilient to cope effectively with unexpected events, recover from crises and even foster future success, through conducting research and developing creative approaches to address the complex and evolving issues that the society faces. Underlying this theme is the acknowledgment that Science, Technology and Innovation are major drivers and enablers of social, environmental, health and economic transformation. The application of knowledge and innovation is necessary to attain sustainable economic growth and competitiveness.

Authors had opportunities to address this broad theme under five sub themes:

1. Education for National Development in a Global Context

Education is a crucial sector for any country, playing a critical role in national development by investing in human capital development. However, the evolving nature of the 21st century, coupled with digitization, have posed challenges to acquiring and imparting knowledge to learners amidst the presence of a wide variety of distorted information. Further, the recent Covid-19 pandemic has brought the need to adapt and respond to the needs of learners as their aspirations keep on changing in this era of globalization of world economies. This points to the need to provide education that is relevant and connected to empowering young people to create jobs, respond to the employability

needs of the current market and advance SDG-*4 of ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all.* Abstracts, papers and posters presented under this sub-theme should focus on education for national development in a global context.

2. Sustainable and Safe Food Systems, Biotechnology and Climate-Smart Agriculture for Healthier Diets

Despite world food production keeping pace with population growth because of the Green Revolution, the United Nations State of Food Security and Nutrition in the World 2022 Report indicates that the number of people affected by hunger has increased with 29.3% of the global population food insecure, and 22% of children under five years of age stunted. Many more have low-quality, unhealthy diets and micro-nutrient deficiencies leading to obesity, diabetes, and other diet-related non-communicable diseases. Food safety and nutrition are inextricably linked. To achieve optimal human health and wellbeing, people must be both well-nourished and free from foodborne diseases. Additionally, current agro-food systems significantly impact the environment, including soil and water resources. Food systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries. Climate change has negatively impacted on production by reducing crop yields, nutritional quality and lowering livestock productivity. Climate-smart agriculture is an integrated approach that aims at increasing productivity, enhancing resilience and reducing greenhouse gas emissions. Biotechnology through genetic engineering offers methods to improve food and nutritional security by raising the quality and yield of crops. Research and development on sustainable practices and solutions are required for achieving food and nutritional security while protecting the natural resources. Therefore, this sub-theme calls for abstracts, papers and posters that focus on how research and innovation can support the use of sustainable and safe food systems, biotechnology and climate-smart agriculture for enhanced food security.

3. Trends in Science, Technology, Engineering and Mathematics

Advances in Science, Technology, Engineering and Mathematics (STEM) are essential pillars and drivers to innovative solutions that are vital to counter challenges due to increased societal needs. The Government of Kenya has an established policy and programme on integration of STEM from early childhood development through to graduate education. Trends in STEM are also major drivers to the advancements in ICT and the 4th industrial revolution that is expected to alter living and working environments. Knowledge, advancement and application of STEM is vital in the development of more effective tools, toolkits, techniques and technologies, for design, development and management of infrastructure, environment, agriculture, ICT and industrial processes, with optimal consideration to resources, society, technical factors and time. Abstracts, papers and posters presented under this sub-theme should address how trends in STEM can be utilized to drive solutions and innovations that address Kenya's identified priorities and other needs for sustainable development**.**

4. One Health Approach, Health System Management, Health Financing, Pandemic Preparedness and Surveillance

The health of humans, animals and ecosystems are closely interlinked and changes in these relationships can increase the risk of new human and animal diseases developing and spreading. Collaboration, communication and coordination is required between the relevant sectors. Ensuring planetary health, proper planning, directing, and coordinating medical and health services, coupled with adequate sources of financing is required to ensure proper health and pandemic control. Further, the Covid-19 pandemic highlighted the need for pandemic preparedness. In the modern interconnected world, safeguarding global health security is vital for maintaining public health for any nation. Emergency preparedness is key to controlling the emerging public health challenges at both national as well as international levels. Surveillance systems, disease modelling and forecasting play a pivotal role in both policy building, disease detection, prevention and response to potential health threats. This sub-theme calls for abstracts, papers and posters that focus on the one health approach, health system management, health financing, pandemic preparedness and surveillance.

5. Environmental, Technical and Policy Approaches in the Context of Climate Change Information and Adaptation for a Resilient Society

The consequences of climate change are on a global scale. Adaptation and resilience are the changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Therefore, this subtheme calls for abstracts, papers and posters that focus on: Restoration in the face of a changing climate; Innovation ecosystem for change mitigation and adaptation in a development context; Ecosystem based adaptation to address climate change among the rural, urban and peri-urban communities; Urban planning and development; Gender and environmental governance; and the Role of Youth in conservation and Green ecosystem infrastructure as a tool in management of peri-urban and other environments.

With Many Thanks,

Signature

Prof George Owour

Message from the Chair,

Conference Organizing Committee

Dr. Miriam K. Charimbu
Chair, Conference Organizing Committee

The Conference Organizing Committee has great pleasure to share with you the Egerton University 15th Biennial International Conference proceedings. The success of the conference was due to the hard work, efforts and commitment of the members within the committee and the secretariat. A big thank you to all authors and co-authors who responded to the call for abstracts. I appreciate all reviewers for providing their technical critique to the abstracts and manuscripts. Special appreciation to all sub theme editors who planned and coordinated the reviewing of all the abstracts and manuscripts that were received. Sincere gratitude to the secretariat team that has facilitated the conference with all the logistics and supported the production of the proceedings. The Egerton University 15th Biennial International Conference was blended with virtual and face-to-face sessions. The conference brought together over 500 partcipants from academia, research institutions and other industry experts in various fields to a common forum. The aim of the conference was to provide a platform for participants to share their experiences and research results, deliberate and exchange innovative cutting-edge development ideas, concepts and actions through interactive panel discussions, keynote speakers, paper presentations, question and answer sessions and exhibitions. Egerton University 15th Biennial International Conference theme "Research for Innovative Solutions in the 21st Century" captures the importance of research, innovation and its outputs in providing solutions to various societal challenges hence building the resilience of the communities. The 15th conference attracted 89 research abstracts and papers categorized under 6 subthemes namely Sustainable and Safe Food Systems, Biotechnology and Climate-Smart Agriculture; Education for National Development in a Global Context; One Health Approach, Health System Management, Health Financing, Pandemic Preparedness and Surveillance; Environmental, Technical and Policy Approaches in the Context of Climate Change and Adaptation for a Resilient Society; Trends in Science, Technology, Engineering and Mathematics and Literature, Language, Culture, Communication and the Creative Economy. Over 100 Authors and coauthors exhibitors from 8 nationalities presented and exhibited their research products during the three days of conference in two parallel physical and virtual sessions. For more information visit our website https://conferences.egerton.ac.ke. for updates and useful information that would make your research journey enjoyable.

Dr. Miriam Karwitha Charimbu,
Chairperson Conference Organizing Committee

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List of Reviewers for the 15th conference proceedings

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- Prof. Nancy Mungai
- Dr. Miriam Charimbu,
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Literature, Language, Culture, Communication and the Creative Economy

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SUB-THEME 1

Education for National Development in a Global Context

Education is a crucial sector for any country, playing a critical role in national development by investing in human capital development. However, the evolving nature of the 21st century, coupled with digitization, have posed challenges to acquiring and imparting knowledge to learners amidst the presence of a wide variety of distorted information. Further, the recent Covid-19 pandemic has brought the need to adapt and respond to the needs of learners as their aspirations keep on changing in this era of globalization of world economies. This points to the need to provide education that is relevant and connected to empowering young people to create jobs, respond to the employability needs of the current market and advance SDG-*4 of ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all.* Abstracts, papers and posters presented under this sub-theme should focus on education for national development in a global context.

Efficacy of Agriculture Teaching Practice Projects in Secondary Schools: The Case of Egerton University Tracer Study

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Abstract

Project Based Learning (PBL) is a participatory approach that equips trainees with transferable competencies for utility. However, the potential of PBL training approach has not been scientifically documented. The efficacy of Agriculture Teaching Practice Projects (ATPPs) in secondary schools was evaluated through a tracer study of Agricultural Education and Extension Degree and Diploma graduates for the last 10 years (2011-2000). Three objectives guided this study. A questionnaire was developed and uploaded on Google forms and thereafter pilot tested for reliability using 36 graduates of 2005 to 2009 cohorts and its Cronbach's Alpha, reliability coefficient was 0.79. Out of the targeted 1,500 respondents, those accessed were 1,408 and 541 of them responded. The response rate was 37.2%. Data collection was done online. Statistical Package for the Social Sciences (SPSS) Version 25 was used to analyze and generate results. From the findings, majority of the respondents established rabbit projects (14.4%), vegetable projects (11.8%) and chicken rearing (10.2%). On transferability of Project Based Training (PBT), 97.4% indicated that they were still using the skills acquired. However, only 70% of respondents indicated that they had established projects in their current stations. Over 91% had established at least a project of whom, 32% had established three or more projects. Among the non-teachers, transferability was 100% as they indicated that they were applying the knowledge and skills learnt from ATPPs. Its worthy noting that only 13.4% of the established ATPPs could be used as a resource to teach across Forms 1-4 while 56.4% of the established ATPPs could only be used in teaching one class only. The study recommends that Egerton University through Department of AGED to deliberately phase out the projects that are short-lived for the benefit of host schools, and review their curriculum to infuse the concept of transferability of PBT.

Key Words: Agriculture Teaching Practice Projects; Graduates; Project Based Learning; Secondary schools

Introduction

Education is considered as the nerve to development as it contributes to economic growth of every nation by nurturing competent graduates through accessible, relevant and quality education (Tindowen et al., 2019). One of the major targets of institutions of higher learning is to improve the efficiency and effectiveness of quality teacher training. To achieve quality teacher training student teachers are not only prepared to teach. In addition, they are prepared in major production

techniques, managerial skills and competencies necessary to function as agricultural trainers (Nataliia & Liubov, 2020).

The level of teacher training in Iceland is key when it comes to preparing teachers in agricultural education. For instance, for one to be certified as a teacher, there are two important levels of teacher training one must fulfill. The first level is a three-year Bachelor's degree then the second level is a two year master's degree training effective in 2013. The five-year programme majorly focuses on the following four key components; collaboration and cooperation which focuses on preparing student teachers to learn skills which will enable them work with their schools upon employment. Second aspect is inclusive education which is a policy that strengthens a teacher's professional skills. The third dimension is professionalism whose aim is to prepare a graduate teacher who will be able to work with his/her school in relation to problem solving and take part in research. The last aspect is diversity of teacher tasks which focuses on creativity in curriculum design (Sigurdardottir et al., 2018).

Teacher preparation in Wales is grounded in University of Wales Trinity Saint David (UWTSD) which is a leader in development of teacher education both in Wales and internationally. The teacher preparation is split into two aspects, teacher training and teacher assessment. Teacher assessment is formative, where student teachers develop projects and portfolios which enable self-evaluation upon time (Weicht & Jónsdóttir, 2021). Teacher training in Russia has an internship programme content is represented by subject-methodological and research training under supervision of experienced teachers (Bocharova, 2018).

A study conducted in Philippines on intern teachers revealed that graduate pre-service teacher who attended internship programmes had better competencies in their work. The interns are assessed in their teaching activities that is classwork and their projects (Tindowen et al., 2019).
In South Africa, internship programme is offered to undergraduate to their final year to offer student teachers smooth transition from class to world of work where they practice what they have been learning (Tonder & Fourie, 2018). Internship programme in South Africa is aimed at promoting acquisition of practical skills by student teachers.

In the East African Region, Tanzania's teacher preparation is done at two levels, Diploma and Bachelor's level which is considered as the highest-level qualification to teach secondary school. Institutions of higher learning have improved pedagogical methods by inculcating the 21st century knowledge and skills in teacher preparation (Ngao & Xiaohong, 2020).

Most of the teacher training programmes in the globe and the region resonate with that of Kenya and especially teacher training in higher learning institutions like Egerton University. Teacher training in Kenya for secondary school students takes four years for Bachelor's degree while three years for those undertaking Diploma courses. From the preceding literature, teacher internship takes place for at least 6 months but in Kenyan scenario for both Diploma and Bachelor Degree student teachers the duration is 3 Months (Katitia, 2015). Egerton University trains teachers of agriculture for both secondary schools as well as technical training institutions. The agriculture teacher training programme has a broad scope with students taking courses from different faculties to meet the training threshold. This study comes at a time when Egerton University is nearing her curriculum review period and also at a time when the Kenya government is implementing the

Competence Based Education system and teacher training institutions are expected to review their teacher training programmes to align to the Competence Based Teacher Framework (CBTF).

The Objectives of the Study

The study aimed at documenting the efficacy of agriculture learning projects prepared by Egerton University Agricultural Education and Extension (AGED) students during teaching practice in host secondary schools.

Research Questions

i. What are the types of agriculture projects initiated by AGED teacher trainees from Egerton University?
ii. What is the extent of transferability of Project Based Training among the AGED trainees after graduation?
iii. To what extent do the AGED trainees' ATPPs address agricultural training in the host schools?

METHODOLOGY

Scope of the Study

This study focused on student teachers of Agricultural education who did teaching practice between 2011-2020 from 10 Teaching Practice Zones. Agriculture teacher training was limited to teacher trainee preparedness, types of agriculture projects initiated by agriculture teachers, extent of use of ATPPs in secondary school training and the extent to which graduates transfer the ATPP skills in the teaching of agriculture.

Sampling Procedure and Sample Size

All the Egerton University AGED graduates between 2011-2020 were traced through snowball sampling and requested to join their cohort WhatsApp groups through which they participated in the baseline survey study. Regular requests to respond to the survey through the WhatsApp groups were made and individual calls to those who had not responded were made.

Data collection Methods

The study employed use of baseline survey questionnaire for data collection while a checklist and an interview schedule were used for phase Two. These instruments were developed by the researchers. The questionnaire captured dependent and independent variables. The structured instruments contained both open ended and closed ended items. They were developed based on the objectives of the study. The questionnaire had three sections with section A sought the respondents' demographic data, section B sought to determine the types of teaching practice projects established by AGED students in their TP schools and Section C sought to determine the transferability of Project Based Training among the AGED graduates.

Data Analysis

The survey link was deactivated after the expiry of the data collection period and data was exported from the Google forms platform to SPSS software (version 25) for validation and analysis. Data

was cleaned, checked for accuracy and completeness, and thereafter, analyzed. Descriptive statistics were generated as per the objectives of the survey. The findings were presented in figures (graphs and charts) and tables. Additionally, qualitative data was summarized and described using frequencies and percentages.

Results and Discussion

Year of Teaching Practice

Results in Table 1 indicate that the highest number of graduates conducted their TP in the year of 2016 (13.7%) and 2018 (12.3%). The year 2017 and 2020 accounted only for 2.3% of the population each.

Table 1: Distribution of Teaching Practice graduates by year and programme of study (n=432)

Year	BSc (AGED)	Diploma (AGED)	Grand Total	Grand Percent
2010	14	7	21	4.9%
2011	33	9	42	9.7%
2012	18	11	29	6.7%
2013	27	21	48	11.1%
2014	23	18	41	9.5%
2015	50	4	54	12.5%
2016	53	6	59	13.7%
2017	2	2	4	0.9%
2018	23	30	53	12.3%
2019	43	8	51	11.8%
2020	5	1	6	1.4%
2021	22	2	24	5.6%
Grand Total	**313**	**119**	**432**	**100.0%**

4.1.5 The Teaching Practice Zone

Table 2 shows that majority of graduates conducted their teaching practice in Eldoret-Kitale (17.4%); Kisumu-Busia-Siaya-Kakamega (17.1%) and Kisii-South Nyanza (16.9%). The zone that had the fewest students on TP was Thika-Kiambu (9%). This is summarized in Table 2.

Table 2: Summary of AGED Graduates' Teaching Practice Zones (n=432)

S/No.	Teaching Practice Zone	Frequency	Grand Percent
1.	Eldoret-Kitale	75	17.4%
2.	Kisumu-Busia-Siaya-Kakamega	74	17.1%
3.	Kisii-South Nyanza	73	16.9%
4.	Kericho-Bomet	46	10.6%
5.	Nakuru West	36	8.3%
6.	Nakuru East	32	7.4%
7.	Nyandarua-Nyeri	31	7.2%
8.	Nairobi-Machakos-Makueni-Kitui	31	7.2%
9.	Baringo-Koibatek	25	5.8%
10.	Thika-Kiambu	9	2.1%
	Grand Total	**432**	**100.0%**

Types of ATPPs among AGED Students

Respondents were asked to indicate the type of ATPP established and the area of focus of the projects. Their responses were as presented in Tables 3 and 4.

Table 3: Titles of the ATPP among AGED graduates

S/No.	Title of the Project	Frequency	Grand Percent
1.	Rabbitry	62	14.4%
2.	Vegetable Production	51	11.8%
3.	Chicken Rearing	44	10.2%
4.	Identification of Weeds	41	9.5%
5.	Soil Profile	39	9.0%
6.	Construction of Calf Pen	36	8.3%
7.	Bee Keeping	29	6.7%
8.	Agroforestry	23	5.3%
9.	Identification of Livestock Breeds	16	3.7%
10.	Construction of a Crush	9	2.1%
11.	Fish Farming	6	1.4%
12.	Identification of Farm Tools and Equipment	6	1.4%
13.	Livestock Feeding	6	1.4%
14.	Preparation of Organic Fertilizers	6	1.4%
15.	Other project titles	<6	13.4%

Majority of the respondents established rabbit projects (14.4%), vegetable projects (11.8%) and chicken rearing (10.2%). The projects that were least established included fish farming, livestock feeding, identification of farm tools and equipment and preparation of organic fertilizer at 1.4% each. The top three projects are short-seasoned in a manner that the interns were able to attain substantial results and write reports within the teaching practice period. The teaching practice duration in Egerton University is 12 weeks.

From the findings presented in Table 4, the focus of the ATPP indicated that livestock production had the highest preference among most of the students on teaching practice at 49.1%. This is in agreement with the earlier findings on Table 3 that most projects were on rabbitry, chicken rearing, calf pen construction and bee keeping which are sections under livestock production. This supports the fact that agriculture is a hands-on subject that focuses on establishment of projects meant for learning, earning income and solving agriculture related problems (Röling, 2019). Over, 70% of AGED students undertook their ATPP in the two broad areas of crop and livestock production, however, the over 23% of projects under instructional media.

Table 4: Focus areas of Agriculture and Biology Teaching practice projects (n=432)

S/No.	Area of focus	Grand Total	Grand Percent
1.	Livestock Production	212	49.1%
2.	Crop Production	111	25.7%
3.	Instructional media like Models, chart, drawings	101	23.4%
4.	Engineering	5	1.2%
5.	Entrepreneurial agriculture	2	0.5%
6.	Trees and shrubs	1	0.2%
	Grand Total	432	100.0%

As the education system transits to Competency-Based Training the institutions of higher learning are expected to embrace problem solving which could be best practiced through the ATPP as sources of training resources in Kenya's secondary schools.

4.3 Transferability of Project Based Training among AGED

The extent of transferability of PBT among AGED graduates was measured depending on whether they were still using the skills acquired from ATPP they had established during TP. Out of the 432 graduates who had established projects in agriculture, 97.4% indicated that they were still using the skills acquired. This is shown on Figure 1.

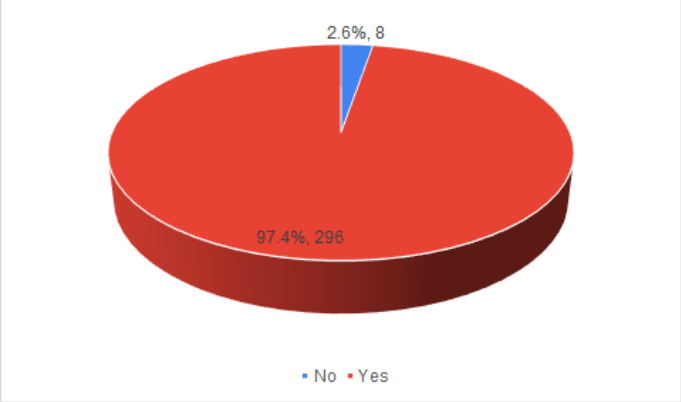

Figure 1: Continued use of skills acquired from teaching practice project training (n=304)

To measure transferability respondents were asked to indicate the number of agriculture projects they had established in their current stations. In Figure 2, 296 respondents indicated that they established projects in their current stations. Over 91% had established at least a project while only 32% had established three or more projects.

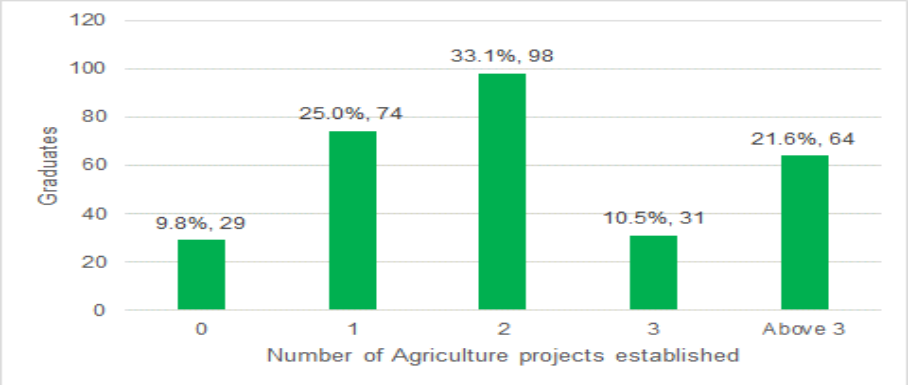

Figure 2: Agriculture projects established in current station (n=296)

Transferability was also measured on the usability of the existing ATPPs as presented in Figure 3. Over 45% of the respondents had existing projects in their current stations. However, over 52% indicated that there were no existing agriculture projects in their schools.

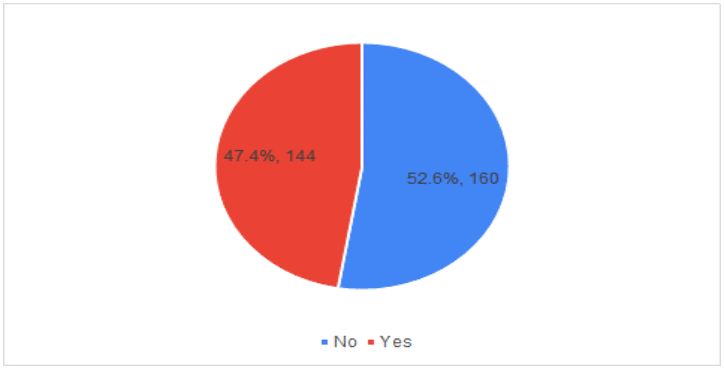

Figure 3: Already Existence of ATPPs (n=304)

Those who had existing projects in their stations were asked to show if they made use of them. The results presented in Figure 4 indicate that 45% of the respondents used existing projects in their schools but at different time spans. Majority at 52.8% had used them in the last one month while 6.9% had used them in the last one year. Those who had used them in the last two weeks and one month were 15.3% and 25% respectively.

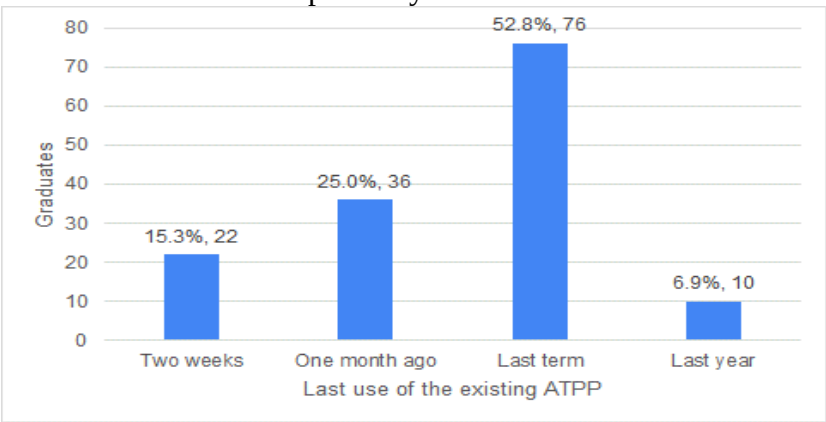

Figure 4: Last used the existing ATPP (n=144)

The same data was analyzed per programme of study as presented in Figure 5 and it was clear that most of the graduates had used the projects in the last one month with 50% and 61.7% both Degree and Diploma graduates respectively.

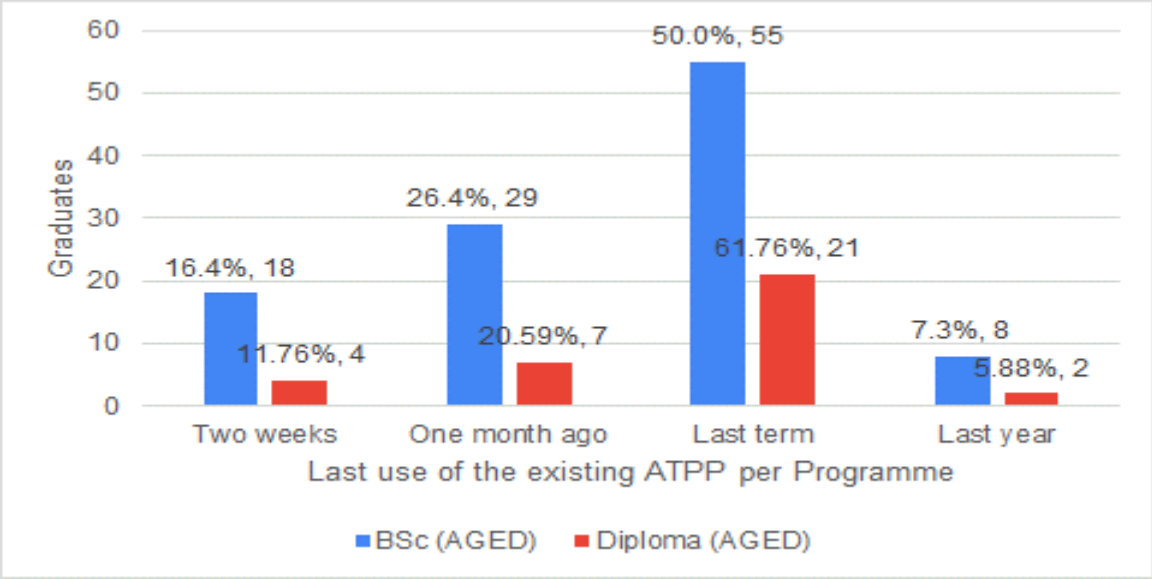

Figure 5: Last use of the existing ATPP by Programme. (n=144)

Transferability was also tested among the non-teachers and 100% indicated that they were applying the knowledge and skills learnt from ATPPs. The non-teachers were also asked about the number of projects they had established in their current stations and majority of them (37.5%) had established over three projects while 12.5% had not established any project. Hence the extent of transferability was low among the non-teachers compared to the teachers.

4.4 Extent of Use of ATPPs by AGED Graduates

Usability of the ATPP was also measured. Respondents were asked to indicate the classes that would be taught using the ATPP established and the results were as presented in Table 5.

Table 5: Major Class(es) where Agriculture subject Teaching Practice Project (ATPP) (n=432)

Class(es)	BSc (AGED)	Diploma (AGED)	Total	Grand Percent
Form 3	80 (25.6%)	23 (19.2%)	**103**	23.8%
Form 1	50 (16%)	21 (17.5%)	**71**	16.4%
Form 1, Form 2, Form 3, Form 4	41 (13.1%)	17 (14.2%)	**58**	13.4%
Form 2	32 (10.3%)	18 (15%)	**50**	11.6%
Form 1, Form 2	30 (9.6%)	12 (10%)	**42**	9.7%
Form 4	13 (4.2%)	7 (5.8%)	**20**	4.6%
Form 1, Form 3	16 (5.1%)	2 (1.7%)	**18**	4.2%
Form 3, Form 4	16 (5.1%)	4 (3.3%)	**20**	4.6%
Form 1, Form 2, Form 3	9 (2.9%)	3 (2.5%)	**12**	2.8%
Form 2, Form 3, Form 4	7 (2.2%)	6 (5%)	**13**	3.0%

Form 2, Form 4	4 (1.3%)	0 (0%)	**4**	0.9%
Form 2, Form 3	6 (1.9%)	2 (1.7%)	**8**	1.9%
Form 1, Form 3, Form 4	3 (1%)	4 (3.3%)	**7**	1.6%
Form 1, Form 4	3 (1%)	1 (0.8%)	**4**	0.9%
Form 1, Form 2, Form 4	2 (0.6%)	0 (0%)	**2**	0.5%
Grand Total	312 (100%)	120 (100%)	**432**	100.0%

Majority of the teacher trainees established projects which could be used in teaching form three despite being expected to mostly teach forms 1and 2. These findings are in agreement with the findings on the title of the TP projects in which most trainees established projects in rabbitry, identification of weeds and chicken rearing all of which are topics taught in form three.

Regarding breadth and scope of the established ATPPs, only 13.4% could be used as a resource to teach across all the four classes while 56.4% of the established ATPPs could only be used in teaching one class either form 1, 2, 3 or 4. Additionally, 6.9% and 23.3% of the ATPPs could be used in teaching three and two classes respectively. Hence the need for AGED trainees to be sensitized on the breadth and scope that enhances the diversity of use of the ATPPs.

Usability was also measured in terms of the number of other subjects that would be taught using the ATPP established. The findings presented in Figure 6 showed that majority of graduates (81.0%) used ATPPs in teaching other subjects.

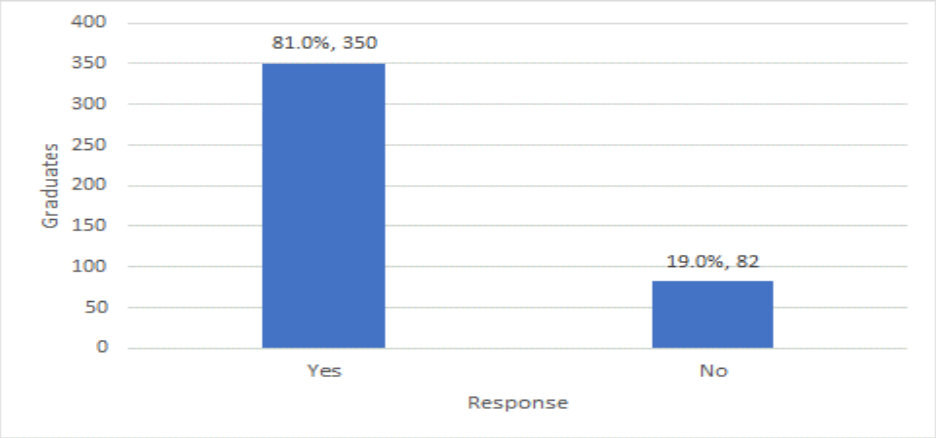

Figure 6: Use of ATPPs in teaching other subjects (n=432)

Of those graduates whose ATPPs were used to teach other subjects, 80.1% and 83.3% were Degree and Diploma holders respectfully as opposed to 19.9% and 16.7% of Degree and Diploma graduates respectfully who did not use the ATPPs to teach other subjects.

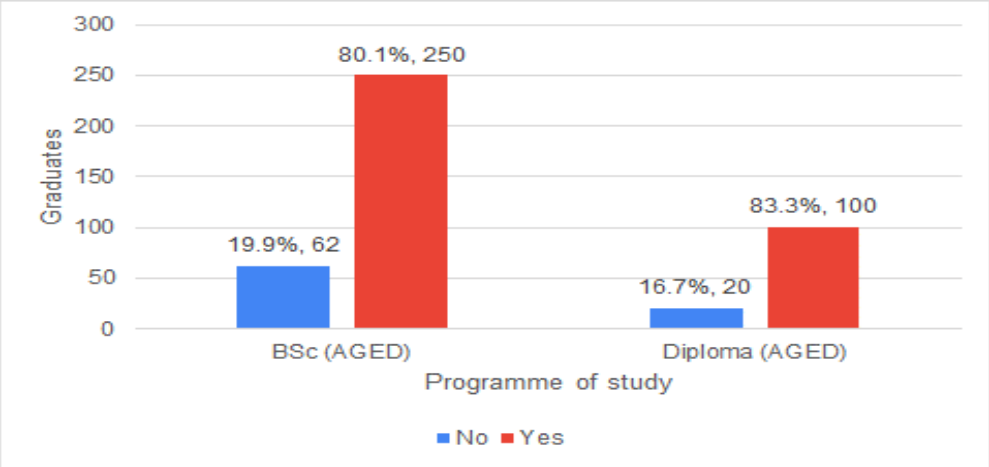

Figure 7: Use of ATPPs in teaching other subjects (n=432)

Transferability was also measured in terms of the other teaching subjects taught using the ATPP. The findings were as presented in table 6.

Table 6: Other subjects taught by ATPP (n=350)

S/No.	Other Subject Taught	BSc (AGED)	Diploma (AGED)	Grand Total	Grand Percent
1.	Biology	97	41	138	39.4%
2.	Geography	47	21	68	19.4%
3.	Geography, Biology	28	8	36	10.3%
4.	Biology, Home science	18	7	25	7.1%
5.	Geography, Biology, Home science	12	5	17	4.9%
6.	Home science	5	3	8	2.3%
7.	Other subjects			**<8**	**16.6%**

Most of the ATPPs were used in teaching biology, which is attributed to the interrelatedness between agriculture and biology subjects. Other subjects that were often taught using the ATPP were geography and home science among others.

Conclusions

Majority of the respondents established livestock projects specifically rabbitry while least projects were fish farming, livestock feeding, identification of farm tools and equipment and preparation of organic fertilizer.

Over 91% indicated to have had established at least a project of whom 32% had established three or more projects. On the use of the projects already existing in schools, 45% of the respondents were already using existing projects in their schools but at different times within the year. The majority 52.8% had used them in the last one month while only 6.9% had used them in the last one year. All those who were not in the teaching profession were found to be applying the knowledge

and skills acquired in the establishment of ATPP and 37.5% had established more than three projects in their work stations.
Most graduates comprising 80.1% and 83.3% for BSc and Diploma AGED respectfully used the ATPP in teaching other subjects. Most of the projects established were meant to teach Form three class with over 60% of the projects being used to teach across most of the classes.

Recommendations

Egerton University through Department of AGED should take a deliberate move to phase out the projects that are short-lived for the benefit of host schools, review their curriculum to infuse the concept of transferability of PBT among the trainees for better acquisition of competencies and promote divergent use of the ATPP developed in schools as teaching resources in different subject areas.

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Knowledge, Attitude, Beliefs and Practice of COVID-19 among Primary and Secondary School learners in Kenya

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Abstract

The first case of COVID-19 in Kenya was confirmed in March 2020. Upon confirmation in Kenya, the Ministry of Health (MoH) through the National Emergency Response Committee on Coronavirus (NERCC) implemented a mix of public health response measures. No study has been conducted in Kenya to establish the knowledge, attitude, beliefs and the preventive behaviours of the pandemic among primary and secondary school learners. Across-sectional descriptive study was conducted where a total of 2798 learners across five counties of Kenya responded to the knowledge, attitude, beliefs and practice (KABP) questionnaire. The data collected was analyzed using both descriptive and inferential statistics, and tested at α=.05. The findings revealed that over 96% of the respondents were able to correctly identify the signs, symptoms and prevention measures of COVID-19. Also, statistical insignificance ($\chi^2 = 8.171$, $p < .05$) existed between counties and the learners' knowledge on prevention methods of COVID-19. On attitude, statistical significant differences ($\chi^2 = 65.79$, $p < .05$) existed between counties in the learners' attitude towards COVID-19. However, statistical significant differences ($\chi^2 = 34.710$, $p < .05$) was found between primary, secondary and special school learners' attitude towards COVID-19. It was established that no significant gender difference (F=2.719, p>.05) existed in the beliefs of COVID-19. Practices towards COVID-19 were statistically associated with knowledge, attitudes and beliefs toward the disease. It was concluded that practices of preventive behaviours among learners can be affected by knowledge, attitudes and beliefs. In effect, these aspects should be considered during pandemics.

Keywords: Attitude, Belief, COVID-19, Knowledge, Practice, School learners

1. Introduction

The COVID-19 global pandemic first appeared in Wuhan, China in December 2019 [1], [2]. Since then, the virus has infected millions globally. The COVID-19 pandemic was declared a Public Health Emergency of International concern (PHEIC) by the World Health Organization in January 30, 2020, meaning the countries of the world were to take urgent and aggressive action against the transmission of the virus. In Kenya, when the first case of COVID-19 was confirmed in early March 2020, the Kenya Ministry of Health (MoH), through the National Emergency Response

Committee on Coronavirus (NERCC) implemented a mix of public health response measures, including messaging to create awareness on preventive measures, such as use of masks, practicing hand hygiene and social distancing [3] and [4]. Other measures included shut down of public places such as educational and religious institutions, dusk to dawn curfew across the country and social gatherings among measures to reduce the spread of the disease. The government also created strict screening points at all locations of entry to the country to detect COVID-19 including roads, airports, buses and train stations [5].

Despite the government efforts to curtail the spread of the pandemic through the various measures put in place, COVID-19 cases continued to rise for some time in Kenya. In fact, responding to the pandemic in Kenya and globally had become a challenge because little was known about the clinically proven treatments and the epidemiological evidence of the pandemic, including its transmission dynamics among others [1]. According to [6], [7] and [8], in times of rising heightened concerns of a disease, health officials and policy makers need to engage the affected population with precautionary behaviours. In fact, [7] notes that in the core of a pandemic, educating, engaging and mobilizing the public to be active participants may likely enhance public health emergency preparedness thus reducing the population's vulnerability. This implies that when the public collectively engage in effective preventive practices that include hand hygiene, limiting mobility, social distancing and putting on face masks, there is a high chance of controlling the transmission of the disease. [4] notes that young people that includes school going children are likely to contribute to the spread of the virus, given their high population and mobility. Hence a routine practice of precautionary behaviours among this population must become a norm. However, to sustain such behaviours critical social, cognitive and psychological factors mediating such behaviours must be taken into consideration. Cognizant of such factors, the researchers therefore conducted a Knowledge, Attitudes, Beliefs and Practice survey on COVID-19 among school learners in Kenya.

According to [3], knowledge and practice are important factors regarding health prevention and promotion. Previous studies on infectious disease epidemics have also revealed that knowledge and awareness [9], [10] and [11] and efficacy beliefs [7] as cited in [12], are motivational factors in the adoption of preventive practices. Other similar studies have established that a higher level of knowledge is positively associated with practice of preventive measures [13], [14], [15], [16] and [17]. Also, attitudes related positively with preventative behaviours (13], [15], [16] and [17]. On gender and behavioural factors related to COVID-19, prior studies have shown that males showed lower knowledge as compared to their female counterparts [3] [4] [18] and [14]. Other studies have revealed that gender affect students' attitudes and practices [3]. Most of these studies were conducted among health professionals and the general public with limited studies conducted among school learners. The five counties were chosen because at the time of the study, they were the counties that had recorded the highest number of COVID-19 reported cases.

2. Objectives

(i) Determine the knowledge, attitude, beliefs and practice of COVID-19 among primary and secondary school learners in Kenya.

(ii) Establish the relationship between primary and secondary school learners' knowledge, attitudes, beliefs and practice of COVID-19.

3. Materials and Methods

3.1 Study Design

The researchers adopted a cross-sectional descriptive design to evaluate the primary and secondary school learners' levels of knowledge, attitudes, beliefs and practices of COVID-19. Descriptive design seeks to establish factors associated with certain occurrence, outcomes or outcome conditions [19], [20]. It is best adapted to obtain personal and social factors, beliefs and attitudes.

3.2 Participants

The study participants were 2798 learners drawn from five counties of Kenya namely: Nairobi, Mombasa, Kajiado, Migori and Elgeyo-Marakwet. Training of research assistants and pilot testing of the data collection tool were undertaken by the researchers. Appropriate data quality checks were conducted regularly throughout the data collection period.

3.3 Measurements

The respondents' knowledge of COVID-19 among school learners was assessed by asking them whether they had heard of COVID-19, correctly indicate some signs and symptoms of COVID-19, and methods used to prevent the spread of COVID-19. Seven (7) signs and symptoms, and nine (9) measures (some correct and others incorrect) were given to the respondents. The respondents were expected to respond to the items by indicating either "Yes" or "No". To measure attitudes related to COVID-19, six (6) items that mainly examined the perceived risk of contracting COVID-19 were developed and the respondents were to respond by "Agreeing", "Not sure" or "Disagreeing". Concerning beliefs, respondents responded to twelve (12) items by Agreeing", "Not sure" or "Disagreeing with them. Finally, precautionary behaviour practices were measured using nine (9) items that mainly covered the COVID-19 preventive measure. In this aspect, the respondents were to respond by indicating either "All the time", "Sometimes" and Not at all". All the respondents' responses were converted into frequencies and percentages. The characteristics of participants considered were: Counties, school category and gender.

3.4 Ethical Considerations

The study ethical approval was obtained from Egerton University Institutional Scientific and Ethics Review Committee prior to conducting the study (EUREC/APP/146/2021). A Research permit was also obtained from the Kenya's National Commission for Science, Technology and Innovations (License No: NACOSTI/P/21/14563). Informed consent was sought from the respondents before collecting information from them. The respondents had an option of terminating the study at any time. The study team protected the confidentiality of respondents. The participation of respondents less than 18 years were consented by the head teachers of their respective schools.

3.5 Data processing and Analysis

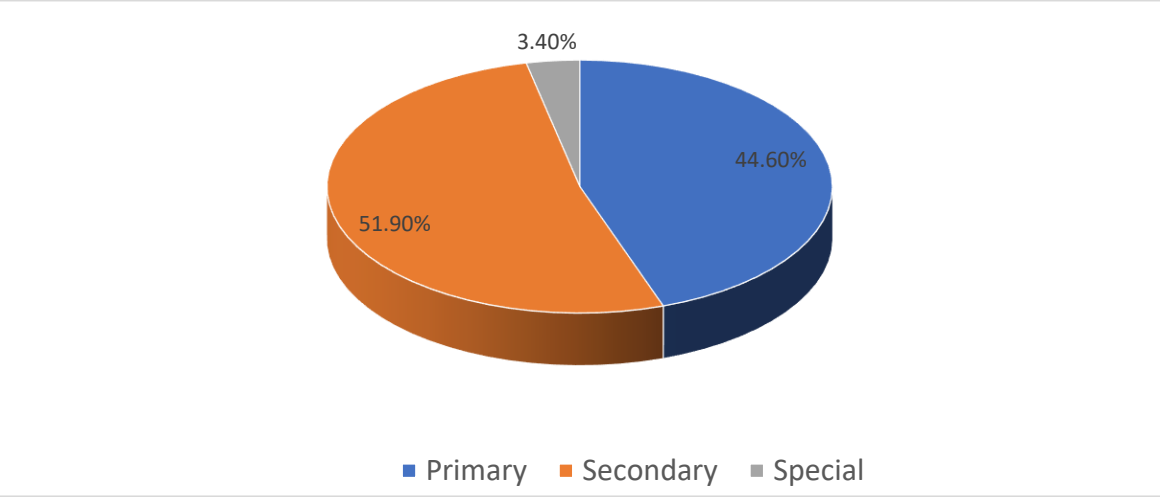
The data collected was analyzed using SPSS to generate basic descriptive tables and tested for differences by category using chi-square tests and where applicable ANOVA and correlations were applied. Tabulations were given as per county, school category, gender. All statistical tests were at α=.05. Prior to data analysis, the data was cleaned in preparation for the descriptive and inferential analyses.

4. Results

4.1 Demographic Characteristics of study respondents

A total of twelve (12) schools were involved in the study in each of the five counties with five (5) being primary, five (5) secondary and two (2) were special needs schools except for the Kajiado County where one special school was involved. In each school, knowledge, attitudes, beliefs and practices (KABP) questionnaire was administered. Data from a total of 2798 learners (primary-1249; secondary-1453 and special schools-96) was collected, coded and keyed in excel for analysis. Figure 1 gives the information on the distribution of learners as per the school category.

Figure 1. Proportion of Respondents per School category



From figure 1, the majority of learners were from secondary school type. The small proportion of special school learners is a reflection of the situation in the country and globally.

4.2 Learners' Knowledge of COVID-19

The knowledge of COVID-19 among school learners was determined by asking them whether they had heard of COVID-19, correctly indicate some signs and symptoms of COVID-19, and methods used to prevent the spread of COVID-19. Seven (7) signs and symptoms, and nine (9) measures (some correct and others incorrect) were given to the respondents. The learners were expected to respond to the items by indicating either "yes" or "no". Table 1, gives the details of the results.

4.2.1 Learners' Knowledge on Signs and Symptoms of COVID-19

From Table 1, over 91% of the learners correctly identified five of the signs and symptoms of COVID-19 out of the seven examined. This implies that the respondents' knowledge level on key signs and symptoms of COVID-19 was high. Loss of hearing and sight which were distracters attracted over 50% of the respondents. This may be an indication that though these symptoms may not have been scientifically identified as those of COVID-19, the respondents may have observed them in some of the COVID-19 patients

Table 1.

Knowledge on Signs and Symptoms

Knowledge Items	Numbers and Percentages of learners' responses	
	Yes F (%)	No F (%)
Fever	2472 (99.0)	26 (1.0)
Loss of appetite	1636(96.1)	67(3.9)
Chest pains	2256(98.8)	27(1.2)
Persistent cough	2407(98.7)	32(1.3)
Loss of hearing	213(55.2)	173(44.8)
Loss of sight	332(67.8)	158(32.2)
Loss of taste	1115(91.3)	106(8.7)

Source: Field data

4.2.2 Learners' Knowledge on Prevention methods of COVID-19

From Table 2, over 98% of the respondents identified correctly each of the key prevention measures. This indicates that the learners had high levels of knowledge about COVID-19 transmission prevention measures with majority of the learners being able to identify correctly eight out of the nine prevention methods presented.

Table 2.

Knowledge on Prevention methods

Knowledge on Prevention methods	Numbers and Percentages of learners' responses	
	Yes F (%)	No F (%)
Wearing a mask properly	2709(99.7)	7(0.3)
COVID-19 Vaccination	2501(99.0)	26(1.0)
Washing hands with soap	2603(99.5)	14(0.5)
Holding each other	327(12.0)	2402(88.0)
Proper Waste disposal/dustbin	1622(59.8)	1089(40.2)
Covering our mouths while coughing	2638(99.8)	4(0.2)
Using safe and clean	2208(81.2)	510(18.8)
Social distancing (1.5 meter)	2664(99.7)	8(0.3)
Not shaking hands	2463(98.8)	31(1.20

Source: Field data

A cross-tabulation between counties done by using chi-square showed statistical significance ($\chi^2 = 26.146, p < .05$) between counties and the learners' knowledge on signs and symptoms of COVID-19. The same statistical significance was observed between primary, secondary and special school learners ($\chi^2 = 34.710, p < .05$). On the contrary, there was statistical insignificance ($\chi^2 = 3.386, p < .05$) between female and male learners. Likewise, on precautionary behaviour measures, statistical insignificance ($\chi^2 = 8.171, p<.05$) was established between counties and the learners' knowledge on prevention methods of COVID-19.

4.3 Learners' Attitude towards COVID-19

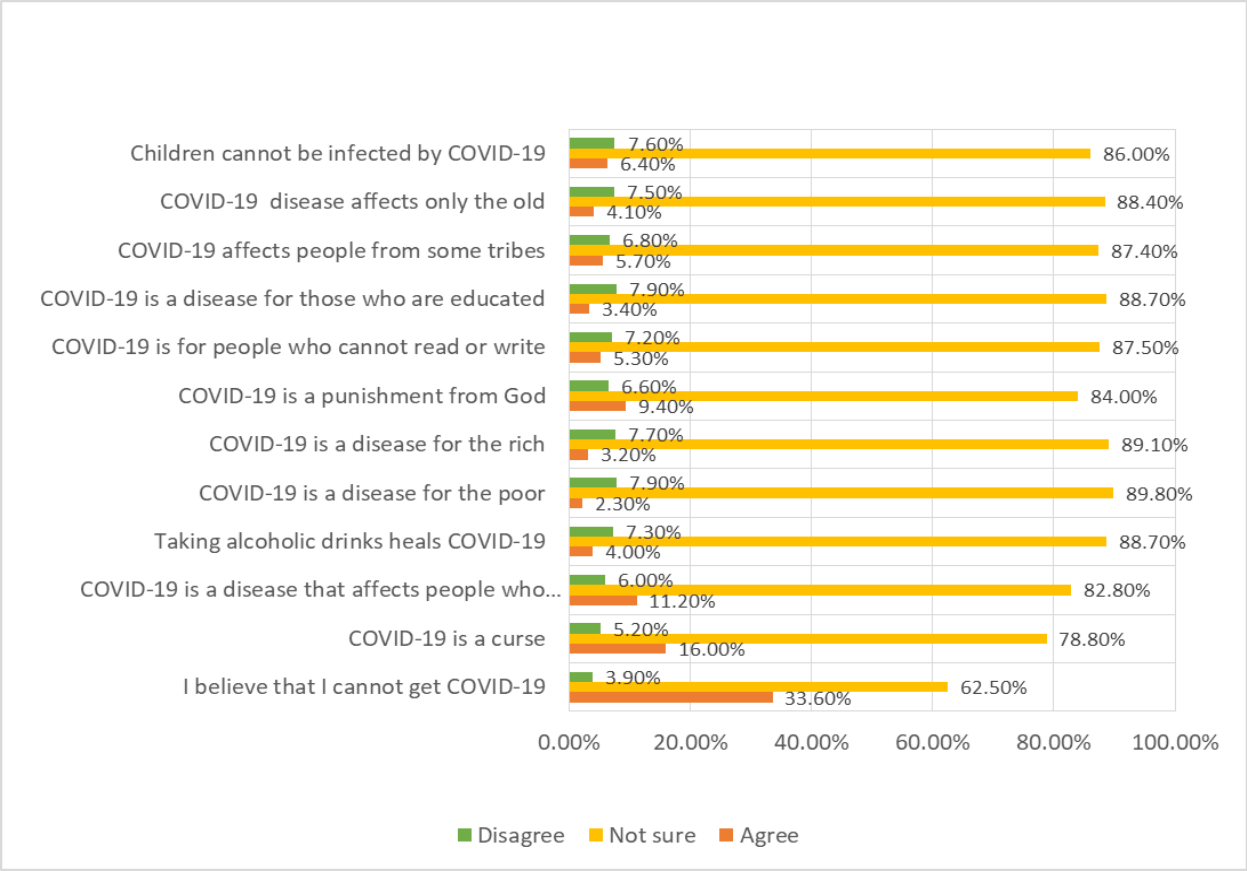
A six (6) item questionnaire was developed to assess the attitude of primary and secondary school learners towards COVID-19. The learners were expected to respond to the items by "Agreeing", "Not sure" or "Disagreeing". Approximately eighty two (81.5% of the learners were in agreement that COVID-19 is more serious than the common flu, will lose friends if they suffered from COVID-19 (52.7%), and people will run away or keep off from them if they suffered COVID-19 (55.1%) and would like to be vaccinated against COVID-19 (53.0%). From these responses, the respondents positively perceived the risk of becoming infected with COVID-19, thus was concluded that this enhanced their positive attitude towards the dangers of contracting COVID-19. A cross-tabulation between counties showed statistical significance ($\chi^2 = 65.79, p < .05$) between counties and the learners' attitude towards COVID-19. Further cross-tabulations showed statistical significance ($\chi^2 = 34.710, p < .05$) between primary, secondary and special school learners in their attitude towards COVID-19. On gender, no statistical significance was established between male and female learners attitude towards COVID-19 ($\chi^2 = 34.710, p > .05$).

4.4 Learners' Beliefs about COVID-19

A twelve (12) item questionnaire was developed to assess the beliefs of school learners on COVID-19. The learners were expected to respond to items on beliefs by "Agreeing", "Not sure" or "Disagreeing."

Figure 3 indicates responses on various beliefs from the learners. The learners were expected to disagree to all the items in order for them to be judged to be having the appropriate beliefs of COVID-19. Interestingly, less than 8% of the learners disagreed to each of the belief items, less than 17% of the learners agreed to the items except the item "I believe that I am not able to get COVID-19" which attracted 33.2% and the majority (> 62%) of the learners were not sure in each of items.

Figure 3. Learners' Responses of their Belief towards COVID-19

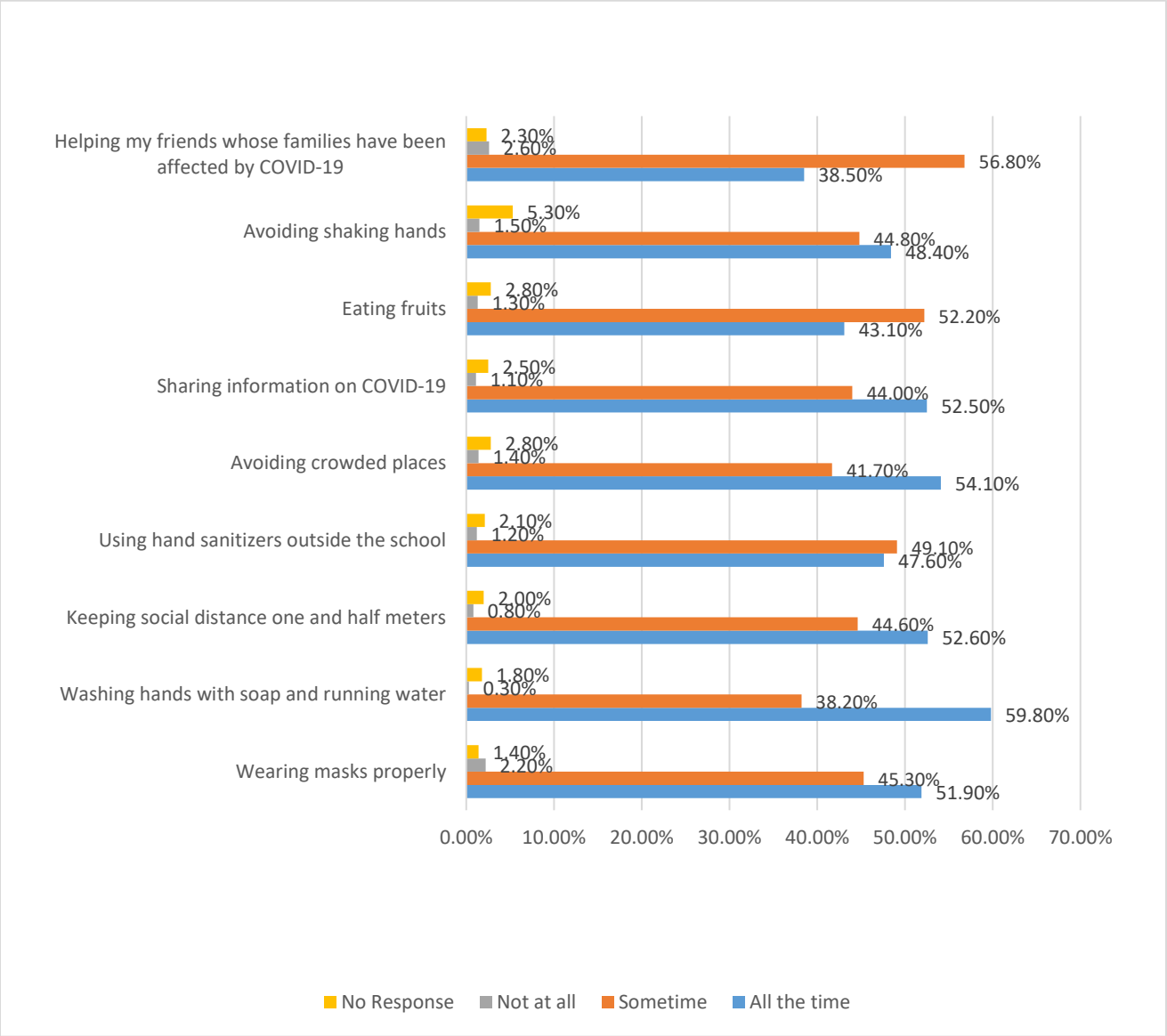


A cross-tabulation between counties showed statistical insignificance ($\chi^2 = 198.8, p > .05$) between counties and the learners' beliefs of COVID-19. Further cross-tabulations showed no statistical significance ($\chi^2 = 60.89, p > .05$) between primary and secondary school learners in their beliefs of COVID-19. Insignificant gender difference ($F=2.719, p>.05$) was also established by the study.

4.5 Learners' Practices for COVID-19

A nine (9) item questionnaire was developed to assess the practices adopted by school learners in the prevention of the infection or spread of COVID-19. The learners were expected to respond to whether they adopted the various practices "All the time", "Sometime" or "Not at all". Figure 4, gives the details of the results.

Figure 4. Proportion of Learners responses to COVID-19 preventive measures



From Figure 4, it is observed that generally over 50% of the learners practiced at all the time the key COVID-19 precautionary behaviour measures that included wearing face masks properly (51.9%), washing hands with soap and running water (59.8%),keeping social distance of one and half meters (52.6%), and avoiding crowded places (54.1%). In the use of sanitizers outside school, a higher proportion of learners (49.1%) indicated sometimes, which may be attributed to the cost of the commodity which, it may have been difficult for most of the participants to afford. Interestingly, avoiding shaking of hands which is a key prevention measure was practiced by only 48.4% of the learners all the time. In fact a worrying proportion (5.3%) of participants did not give a response on this, indicating not sure of what to say. A cross-tabulation between counties showed statistical insignificance ($\chi^2 = 105.5, p > .05$) between counties and the learners' practice of COVID-19 measures. Further cross-tabulations between school levels showed no statistical significance ($\chi^2 = 22.46, p>.05$) between primary, secondary and special school learners and the

practice of COVID-19 measures. On gender, significant difference (F=.906, *p*<.*05*) was recorded between male and female learners in the practice of COVID-19 measures, with the female learners showing a higher percentage of adoption of positive behaviour as compared to their male counterparts.

4.6 Relationship between Learners' Knowledge, Attitudes, beliefs and Practice

In the study, further analysis was done on the relationship between knowledge, attitudes, beliefs and practice (KABP). The findings are presented in Table 3.

Table 3. *Correlations between Knowledge, Attitude, Beliefs and Practice*

Variable	Knowledge on Signs and symptoms	Knowledge on Prevention Methods	Attitude	Belief	Practice
Knowledge on Signs and symptoms score	1				
Knowledge on Prevention Methods score	.038 (*p*>.05)	1			
Attitude score	.032 (*p*>.05)	.035 (*p*>.05)	1		
Belief score	.81*(*p*<.05)	-.027 (*p*>.05)	.006(*p*>.05)	1	
Practice score	.048* (*p*<.05)	.076* (*p*<.05)	.184*(*p*<.05)	.122*(*p*<.05)	1

From Table 3, the findings reveal that knowledge on signs and symptoms significantly related to beliefs (r=.081, p <.05) and practices (r=.048, *p* <.05). In effect, those with higher knowledge in signs and symptoms were more likely to have the right beliefs and were more likely to adopt prevention practices compared to those with less knowledge. This implies that providing sufficient and precise information during a pandemic helps in correcting inaccurate and misguided information thus correcting existing beliefs emanating from culture and systems during a health crisis. In the same vein, the indirect effects of knowledge on preventative behaviors significantly mediated the COVID-19 practices (r=.184, *p*<.*05*). In addition, attitudes and beliefs significantly influenced the adoption of COVID-19 prevention practices. Of greater observation is that knowledge, attitudes and beliefs significantly influenced the practice of preventive behaviours.

5. Discussion:

On the knowledge of COVID-19, a high proportion of the learners correctly identified five of the signs and symptoms of COVID-19 out of the seven examined. This implies that the respondents' knowledge level on key signs and symptoms of COVID-19 was high. These findings corroborate those of [21] where their study established that 99 % of their respondents had good knowledge of COVID-19. Other similar studies showed the same trend [22], [23], [24], [25], [3] [26], [27]. According to [28], knowledge is a significant factor regarding health prevention and promotion. This involves identification of symptoms and available methods of treatment and consequences.

In effect, knowledge can play a crucial role in enhancing the practice of public preventive behaviour [12]. On prevention measures, learners revealed a high levels of knowledge about COVID-19 transmission prevention measures. The finding supports those of [4], which found that over 88% of the respondents of their study correctly indicated the COVID-19 prevention methods. On attitude towards COVID-19, over 52% of the learners had appropriate attitude towards the disease. This suggest that majority of the learners perceived the risk of becoming infected with COVID-19 thus were more willing to adopt measures aimed at curtailing the transmission of COVID-19. This study findings contradict those of [29] who established high prevalence of poor attitude towards COVID-19 among their study participants in Rwanda. Other studies have reported low prevalence of poor attitude in Saudi Arabia [30] and China [31]. Concerning beliefs, the current study found low levels efficacy beliefs of COVID-19 among the school learners with most of them taking a neutral position. According to [12], persons with higher efficacy beliefs of COVID-19 are more likely to effectively practice the appropriate prevention measures. Therefore, efficacy beliefs have significant effect on disease preventive behavior. In fact, [12] further established that efficacy beliefs significantly mediated the relationship between knowledge of COVID-19 and three preventive behaviours (wearing a facial mask, practicing hand hygiene, and avoiding crowded places). Individuals form self-efficacy beliefs by interpreting information regarding their own capabilities. If people believe they can manage threats that come on their way they are not distressed by them, but if they believe they cannot control potential threats, they experience high anxiety. In this study, the majority of the respondents indicating "not sure" implies that either the learners were experiencing a high anxiety of the pandemic or they still lacked sufficient knowledge about COVID-19. In effect, pandemic related efforts should prioritize populations who have low efficacy beliefs, particularly the youth and children who may have low knowledge levels of COVID-19. Insignificant difference between primary, secondary and special school learners, and their gender in beliefs of COVID-19 was established by the study. These findings are in support of [4] study which established that majority of the youth in Kenya adopted more positive practices on health protocols to avoid the COVID-19 despite some beliefs within communities.

On practices, over 50% of the learners practiced at all the time the key COVID-19 precautionary behaviour measures. The findings are in line with a study conducted by [4] which established that in terms of practice, majority of the youth in Kenya adopted more to positive behaviour practices to avoid infection that included washing of hands (99%), and use of masks (98%). In the use of sanitizers outside school, a higher proportion of learners (49.1%) in this study indicated sometimes, which may be attributed to the cost of the commodity which, it may have been difficult for most of the participants to afford. According to [5], many of the recommended practices to control the spread of COVID-19 present particular challenges for persons living in poverty. Interestingly, avoiding shaking of hands which is a key prevention measure was practiced by only 48.4% of the learners all the time. In fact a worrying proportion (5.3%) of participants did not give a response on this, indicating not sure of what to say. This could be attributed to the African culture which the participants have been brought up in where shaking of hands is a common form of greeting. Thus practices on preventative measures should be improved in the general population cognizant of the cultural norms.

The statistical insignificance between counties and the learners' practice of COVID-19 measures contrasts a study that was conducted on practice of COVID-19 measures among households in Mombasa and Kilifi counties of Kenya where statistical significance was revealed among the two counties [3]. In this study, no statistical significance was established between primary, secondary

and special school learners and the practice of COVID-19 measures. This contrasts other earlier studies, where positive adoption behaviours to COVID -19 control measures were linked to higher education levels [24], [32], [25]. On gender, significant difference was recorded between male and female learners in the practice of COVID-19 measures, with the female learners showing a higher percentage of adoption of positive behaviour as compared with their male counterparts. The findings corroborate with those of [3] [25] and [24] which established that females were more likely to practice measures put in place to combat COVID-19 which contrast findings of similar studies in India and Cameroon where females were found to be less likely to practice key preventative behaviours compared with their male counterparts [33], [34].

Finally, the study established that knowledge, attitudes and beliefs significantly influenced the practice of preventive behaviours. This implies that promoting preventative behaviours toward COVID-19 would require promoting knowledge, attitude and beliefs among affected populations [12]. Moreover, according to [10], [11] and [13] as cited in [12] noted that earlier studies on infectious disease epidemics showed that knowledge and awareness motivated people to adopt preventive behaviours.

6. Conclusion

i. There was high basic knowledge of COVID-19 signs and symptoms and preventive measures among primary and secondary school learners. Thus, it is paramount to close knowledge gaps in a population in order to reduce gaps in health behaviors and outcomes.
ii. Knowledge, attitudes and beliefs have a significant influence on practicing preventive behavior, implying that adoption of preventive behaviours towards COVID-19 would require promoting knowledge, attitudes and beliefs among the affected populace

Recommendations

i. During health crises, there is need to consider beliefs stemming from culture and system which if they are in conflict with disseminated health information, they may profoundly affect behaviour change initiatives.
ii. Public health education programmes tailored for learners in school and aimed at improving a pandemic's related knowledge, attitude, beliefs and practice should be prioritized in all counties of Kenya during emergency responses.

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Authors' contributions

All the authors substantially contributed to the preparation and approved the final version of the manuscript.

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Effects of Simulation Teaching Technique on Co-Educational Secondary Schools Students' Attitude Towards Learning Physics in Buuri-East Sub-County, Kenya

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Abstract

Learner's performance on secondary school physics in the Kenya National Examination Council is below average. This poor performance may be attributed to conventional teaching techniques that are applied in teaching physics that leads to students having a negative attitude towards the subject. Hence, this study sought to investigate the effect of Simulation teaching technique on students' attitude towards learning physics specifically on the topic Magnetism. Solomon-four, non-equivalent research design was used. Four schools were randomly sampled from 16 co-education day secondary schools in Buuri East Sub-County of Meru County, Kenya. The sampled schools were randomly assigned to experimental and control groups. A total of 123 students from the sampled schools were involved in the study. Students Attitude Questionnaire (SAQ) was used to collect data on students' attitude towards learning physics. The instrument was validated and pilot tested for use in data collection. Cronbach alpha was used to estimate the reliability of SAQ, and a reliability coefficient was found to be 0.73. Both descriptive and inferential statistics were employed in data analysis, these included mean-score, t-test and Analysis of Variance (ANOVA). All statistical tests were tested at a 0.05 alpha level of significance. The results from post-test mean scores for control groups were as shown (Control 1 MS=2.77, Control 2 MS=2.275) those of experimental groups (Exp 1 MS=2.88, Exp 2 MS=2.85). These results revealed that the students exposed to the treatment improved their attitude towards learning physics. However, the difference was not statistically significant. The results also showed a difference between boys and girls attitude towards learning physics though it was not statistically significant. The study recommends that physics teachers should embrace the use of simulation in teaching to boost students' attitude towards learning physics

Keywords: Attitude, Education, Gender, Physics and Simulation.

Introduction

Physics is a branch of science that deals with the relationship between matter and energy. Today people's lives are heavily dependent on machinery, industry and technology. Ngatia et al. (2019) point out that technology that is continually transforming the world can be directly traced back to research in physics. These foundations necessitate people with knowledge and skills in Physics, hence the need to support Physics education in Kenya. Adeyemo (2011) notes that, it is essential for every child to be given an opportunity to acquire knowledge and concepts in Physics.

Despite the importance of Physics, students' achievement in this subject has been below average as attested by Kenya Certificate Secondary Education (KCSE). There are a number of reasons that have been raised to explain the poor students' achievement in Physics. One of the factors that have been raised is conventional teaching techniques. In this study conventional teaching techniques means any techniques that a teacher uses that does not involve models such as simulation or a

practical and limits students participation in the learning process. The poor achievement in this subject has lead learners to developing negative attitude towards learning physics. According to Guido (2013), attitude is a tendency for individuals to organize thoughts, emotions and behavior towards a psychological aspect. In the study attitude refers to the way one thinks and feels towards physics which may be either positive or negative.

Mushinzimana, et al. (2016) found that the performance of physics students is poor at the department of physics in Nyarugenge campus, Rwanda, due to negative attitude towards the subject. It is, therefore important for teachers to instill the right attitude towards a subject in students. Medine (2016) argues that teachers can change views of students towards physics in a positive way. This is possible if they are well equipped with the right teaching techniques and resources. This study seeks to fill this gap by determining the effects of simulation teaching technique on students' attitude towards learning physics.

Some students form a negative attitude towards physics long before enrolling in secondary school due to the opinion they get from their parents, elder siblings, friends and even teachers (Kahare, 2011). Ezeliori (2004) observes that in most countries, from birth girls are made to believe that science is a male student's subject by societal stereotypes. This denies them an opportunity to experience the environment to explore, which is a pre-requisite to learning of science. This has contributed to most girls shying away from science subjects especially physics and developing an attitude that science subjects are meant for boys. The few that select the subject do not perform well as compared to the boys. This study also sought to determine the effects of simulation teaching technique on students' attitude towards learning physics by gender.

Simulation is the use of computer to predict outcome of a real-life situation using computer model. Computer simulation technique transforms physics concepts from theoretical to practical form. According to Pfefferova (2015), simulation is a technique that helps students comprehend better in basic features of oscillatory motion and improved their attitude towards physics. Students who were taught using computer simulation technique in Physics had higher mean acquisitions of practical skills and a positive attitude towards learning Physics (Jayantha, 2018). In this study, the concept of Magnetism was used due to the abstract nature of its concepts. This topic is also tested in paper 2 physics which is the worst performed paper among the three physics papers as per K.N.E.C reports. It is also a crucial topic since it forms a foundation for other topics taught in forms three and four physics.

Purpose of the Study

The purpose of this study was to determine the effects of simulation teaching technique on students' attitude towards learning physics. It also intended to ascertain if simulation teaching technique has any effect on students' attitude towards learning Physics by gender.

Objectives of the Study

This study was guided by the following objectives

(i) To compare students' attitude towards learning physics between students taught through simulation technique and those taught through conventional technique in Buuri East sub-county.

(ii) To investigate if there was gender difference in students' attitude towards learning physics when taught physics through simulation technique.

Hypotheses of the Study

The following hypotheses were tested during the study

$H0_1$: There is no statistically significant difference in students' attitude towards learning physics for those students taught through simulation technique and those taught through conventional techniques in Buuri East sub-county.

$H0_2$: There is no statistically significant gender difference in students' attitude towards learning physics when taught through simulation technique.

Theoretical framework

The research was guided by dual coding theory proposed by Allan Paivio (1986) . He developed this theory from the ideal that formation of mental images aids in learning. According to this theory there are two ways a person could learn this through verbal associations and visual imagery. Visual and verbal information are processed differently and along distinct channel in the human mind. They create separate representations for information processed in each channel (Sternberg, 2006). However, Human mind can code information as visual, verbal or both. The codes are used to organize incoming information that can be acted upon, stored and retrieved for use. Coding information in two different ways increases the chance of remembering that information as compared to coding in just one way. Individuals who dually code information presented are more likely to recall the information when tested at a later date. Simulation teaching technique is a technique that uses both verbal and visual information in teaching. This gives a chance to code the information received as either verbal or visual or both. Some Physics concepts are so abstract and presenting them using visual images supports the verbal presentation, this may make the abstract concepts more concrete. This helps the learner to conceptualize concepts easily, which leads to better performance and in turn the learners develop a positive attitude towards learning physics.

Research Methodology

The study employed Solomon four non-equivalent control group research design. Four schools were randomly sampled from the 16 co-educational public secondary schools in Buuri Sub-County of Meru County, Kenya. Stratified sampling was used to group the qualifying schools into four strata, this assisted in controlling diffusion effect. The sub-county has four wards which represented our four strata for this study. One school was selected randomly from each strata, this yield four sample schools that were used in the study. Simple random sampling was used to allocate the four schools into either experimental and control group. Two of the schools were randomly assigned to experimental groups while the other two were assigned to control groups.123 form two students from the sampled schools took part in the study. This is because the form the topic under study is in form two. A Student Attitude Questionnaire (SAQ) was developed, validated and pilot tested for use in data collection. The reliability coefficient of SAQ was 0.7. A pretest was administered to students in one control and one experimental school. Simulation teaching technique was then applied on the experimental groups as treatment for three weeks. Thereafter, a posttest SAQ was administered to students in all the four groups. SAQ results were then scored and analyzed using ANOVA, and t-test at α level of 0.05. Figure 1 shows the representation of the Solomon Four Non-Equivalent Control group design.

Group	Pre-test	Treatment	Post-test
E1	O1	X	O2
E2	-	X	O3
C1	O4	-	O5
C2	-	-	O6

Figure 1**: Solomon's Four Non-Equivalent Control Group research design**

Source; Fraenkel and Wallen (2011)

E1- Experimental group one

E2- Experimental group two

C1- Control group one

C2- Control group two

O- Indicates observations or outcomes at pre-test and post-test phases

X - Indicates treatment

----------Non-Equivalent Control Group Design

Results and Discussion

The SAQ scores were recorded and constituted data used in the study. Data was analyzed using ANOVA and t-tests at α level of 0.05. A statistical package for social sciences (SPSS version 22) was used in data analysis.

Results of the Pre-tests

Pre-testing was carried out with, two groups sitting for the pre-tests one control group and one experimental group .The aim of the pre-test was to ascertain whether or not the students selected to participate in the study had comparable characteristics before presenting the treatment. Table 1 shows the results of the comparison for pre-test SAQ scores between Experimental and Control groups.

Table 1: SAQ Pre-test Results Between Experimental and Control Groups

Variable	Group	Mean	SD	t-value	p-value
SAQ	C1	2.7419	0.239	-.190	0.417
	E1	2.7502	0.221		

The results from Table 1shows that the SAQ pre-test mean score was not statistically significant different since at the level of at 0.05 significance p=0.417.This means that the groups used in the study were comparable. They had similar entry behavior and this made them appropriate for the study. Similar analysis was done based on gender. The differences in Attitude towards learning physics pre-test by gender were also examined during the pre-test analysis. Boys and girls pre-test scores in SAQ from Control group1 and Experiment group 1 were compared. Table 2 shows summary of the pre-test scores on SAQ based on students gender.

Table 2: Independent Sample t-test Scores on SAQ Based on Students Gender

Scale	Group	N	Mean	SD	t-value	df	p-value
SAQ	Boys	28	2.69	0.18	1.002	58	0.32
	Girls	32	2.55	0.17			

The results for SAQ showed a difference in boys and girls means score in favor of boys. This difference was however not statistically significant since the p value was 0.32 which is greater than .05 at a level of α=0.05 significance. Only one control group and one experimental group were subjected to the pre-test. This helped the researcher to establish similarities of the groups before introducing the intervention and generalize the findings to the groups which were not given the pre-test.

Students' attitude towards learning Physics.

To determine the effect of simulation teaching technique on students' attitude towards learning physics an analysis of students' post-test SAQ scores was carried out. Table 3 shows SAQ post-test mean score which were obtained by students in the four groups

Table 3: Students SAQ, Post-test Mean Scores

Group	Mean Score	N	SD
C1	2.7798	32	.19975
C2	2.7542	31	.23813
E1	2.8869	32	.24424
E2	2.8554	28	.23703
TOTAL	**2.8184**	**123**	**.23379**

The results of Table 3 shows that the post-test mean scores for control groups (C1 MS=2.7798,C2 MS=2.7542)were lower, than those of experimental groups (E1 MS=2.8869,E2 MS=2.8554). The results indicate that the experimental groups had a better attitude towards learning physics than the control groups. To establish whether the difference was statistically significant, a one-way ANOVA was performed. Table 3 shows the results obtained from the analysis of one-way ANOVA.

Table 4: ***ANOVA Results of the SAQ Post-Test Scores***

Sources of Variation	Sum of Squares (SS)	D.f	Mean Squares	F-ratio	p-value
Between groups	.364	3	.121	2.291	.082
Within groups	6.304	119	.053		
Total	**6.668**	**122**			

The result from Table 4 shows that the p-value is .082 which is above 0.05.This indicates that there is no statistically significant difference among the four groups. The analysis from this study implies that the null hypothesis H_o2 which states "There is no statistically significant difference in students' attitude towards learning physics between those taught through simulation technique and those taught using conventional techniques" is accepted. The findings of the study showed there was a difference in attitude towards learning physics for those exposed to the treatment, in favor

of those who were exposed to the treatment. However after further analysis the difference was found not to be statistically significant.

Attitude towards learning Physics between boys and girls

The study sought to find out whether there was any statistically significant difference between girls and boys attitude towards learning physics for those taught through simulation teaching technique. The analysis of the experimental groups was conducted to find out if there is a difference in attitude towards learning physics for boys and girls. Table 4 shows the independent sample test of the post-test SAQ scores for boys and girls exposed to simulation teaching technique.

Table 5: *SAQ Scores for Boys and Girls Exposed to Simulation Teaching Technique.*

Gender	N	Mean	SD	t-value	Df	p-value
Boys	28	2.89	0.263	0.588	58	0.25
Girls	32	2.85	0.220			

Table 5 shows the results of post-test SAQ mean score for boys and girls as 2.89 and 2.85 respectively. From the results the boys performed slightly higher than the girls. The results from the independent sample T-test shows that the p-value was 0.25 this implies that the difference between the girls and boys mean score was not statistically significant at $\alpha=0.05$. With reference to the results obtained the null hypothesis H_O2 which states that there is no statistically significant gender difference in students' attitude towards learning physics when taught through simulation technique is accepted. This means that simulation teaching technique doesn't favor any gender in terms of attitude towards learning physics.

Discussion of results

The study results indicated that E1 and E2 had a mean score of 2.8869 and 2.8554 respectively. C1 and C2 had a mean score of 2.7798 and 2.7554 respectively. The hypothesis of the study sought to determine whether there is a statistically significant difference in students' attitude towards learning physics between those students who were taught by simulation technique and those who were taught through conventional teaching technique. The results indicated a difference in the means of experimental groups and control groups in favor of the experimental groups. Though the difference was not statistically significant, there is improvement in attitude towards learning physics, by the experimental groups which can be attributed to the use of simulation teaching technique.

There are other studies that have shown significant difference in learners attitude when they were exposed to simulation teaching technique. Abdulmumini (2018) stated that simulation model technique is more effective in teaching of science and technology subjects as well as in producing desirable attitudes in students and teachers respectively in his research on effect of simulation model on attitude, retention and performance in qualitative analysis among secondary school chemistry students. Issa and Jana (2021) in their research on Examining the Use of PhET Simulations on Students' Attitudes and Learning in General Chemistry II found out that interactive simulations have an overall positive impact on students' attitudes and perceptions about learning, simulations promote students' development of conceptual understanding of chemistry

concepts and content, simulations seem to promote and facilitate learning and understanding of abstract concepts, and simulations furnish learning opportunities.

The findings also revealed that there was no statistically significant difference in attitude between boys and girls who were exposed to simulation teaching technique. Although findings from the study reveal that male students had an improved attitude towards learning physics than their female counterparts the difference was not statistically significant. The findings of this study are in agreement with Hussaini et al (2015) study who found out that male and female student do not differ in the attitude towards science. Kabiru (2020) findings on effect of interactive simulation on attitude and academic achievement in mathematics also agrees with this study findings he found that interactive simulation strategy for teaching mathematics did not show any significant difference in attitude and achievement in mathematics amongst male and female students

Some education science researchers have contradicted this study results there have found a significant differences in attitude towards science and technology between boys and girls. Kay (2008) noted that girls respond very positive to online learning environments. He argues that inserting computer simulation learning environments in the science lessons in school is a possible measure to influence girls' attitudes towards science and technology. Chen and Howard (2010) posited that simulation teaching techniques influences the attitude of students towards science after exposure positively. This study shows that computer simulation teaching technique bridges the gap in the attitude of male and female students towards learning physics. This is because there was no statistically significant difference in the attitude of male and female students who were exposed to the treatment. It gives girls an equal opportunity to learn physics and get placed to STEM careers without leaving the boys behind

Conclusion and Recommendations

From the findings, it is evident that simulation teaching approach has a positive effect on the physics attitude though not significant. The technique should be included in the teaching of physics in the secondary schools to improve the student attitude towards learning physics. The physics curriculum developers should also develop the teaching-learning materials in line with the simulation teaching technique to help the learner easily conceptualize abstract physics concepts.

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Harnessing Adaptive Value-Based Education Model within the Era of the Fourth Industrial Revolution (4IR) in Kenya

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Abstract

The world today has entered in an era of the Fourth Industrial Revolution (4IR) characterized by artificial intelligence-AI, virtual interaction, digital channels, among others. This new culture is expected to alter the way we live, perceive and interact with others hence challenge, change and disrupt every sector of our lives. Consequently, the resulting new social-cultural, moral and spiritual values have introduced to the digital generation new choices and worldviews, philosophies and cultural orientations. As such, this has created a contemporary need for the educationists and other education stakeholders to guide the latter generation through development of a value-based education. Hence, the need to harness adaptive value-based education model within the era of the fourth industrial revolution in Kenya is a request to the education industry to rethink of educational paradigms that promote long term character development in the advent of post-modern fourth industrial revolution era. This review paper aims to develop and recommend a value-based education model in the era of the fourth industrial revolution in 21st century societies, alongside assessing some of the challenges and opportunities in the education industry in the era of fourth industrial revolution. Guided by the Howard Gardner's Multiple Intelligences theory and John Dewey's social constructivism theory, the paper uses thematic content analysis of various literature on fourth industrial revolution, and holistic value-based research work to evaluate the nature of value-based education in the Kenyan context. It was found that although Kenya is on the right trajectory in the global context to implement the objectives of fourth industrial era, however, there is need to emphasize training and acquisition of social and moral values in the Kenyan learners that will complement the digital and technological skills in the global context. Ultimately, it is anticipated that such value-based education model will make the 21st century consumer of the 4IR more relevant, competent and adaptive to navigate through the challenges revolving around the new global cultural contexts. The paper hence, challenges the planers, theorists and other stakeholders in the education 4.0 era within the Kenyan context, to design and actualize value-based curriculum models that meets the holistic aspects of a 21st century Kenyan human capital.

Key Words: Adaptivity, Fourth industrial revolution, Opportunities and Challenges, Value-Based Education.

Introduction

The globe has experienced emergence of various industrial revolutions since 16th century. According to Rembang (2021), this phenomena was birthed with the emergence of the first industrial revolution (1760-1840) characterized by steam energy and mechanical production machine; second industrial revolution (1870-1914) characterized by mass production and electrical energy; third industrial revolution (1969-2000) characterized by automation, computer and electronic;, and the fourth industrial revolution (2000- to present) characterized by among others cloud computing, virtual interaction, big data analysis, Internet of Things(IoT), artificial

intelligence, digital channels, autonomous robots, cyber security, and system integration. With each stage of revolution, various value changes have been left behind. As such, the resulting new culture often alters the way of life, the perception and interaction with others.

Consequently, this challenge, change and disrupt every sector of our lives among them education sector leading to the emergence of new cultural patterns and value systems. As such, the resulting new social-cultural, moral and spiritual values have introduced to the digital generation new choices and worldviews, philosophies and cultural orientations. In such a context, the optimists of 4IR are excited about new culture's opportunities out there as it will bridge the global knowledge gap. However, the skeptics are cautious of the challenges and the potential risks awaiting the fourth industrial culture as it raises the question of inclusivity and equitable access to quality education for all learners as well as the risk of bleaching the moral fabric of the society. This has created a contemporary need for the educationists and other education stakeholders to guide latter generation through development of adaptive value-based education that emphasizes imparting ethical, moral and societal values alongside academic knowledge, empathy, social responsibility and fostering character development for holistic development (Kagema, 2022).

Multiple Intelligences theory in adaptive Value-Based Education

According to Howard Gardner's theory, learners possess multiple minds systems that encompasses various modalities, encouraging diverse teaching methods to accommodate different types of intelligence. Like Dewey's social constructivism theory, Gardener's multiple intelligence theory proposes that curriculum should build an orderly sense of the world where multiple intelligences are developed with the purpose of carrying out different task, progress in different domains, and solve diverse problems in a holistic manner, (KICD, 2017).

At the core of the fourth industrial revolution, digital networks, interactive technologies, data literacy, technological literacy, and human literacy among others, are considered to be the competencies needed to face the industrial revolution 4.0 (Jalinus et. al., 2021). For holistic character development, the learner needs to be equipped with personality values skills alongside post-modern multi-cultural technological skills. Exposure to such value-based education values will make the 21st century consumer of the 4IR more relevant, competent and adaptive to the challenges revolving around the new post-modern cultural contexts.

Education in the era of Fourth Industrial Revolution-4IR

Various definitions have been given on what is education. However, every society has diverse approach, objectives, and varying methodology to their form of education. Hence, it becomes hard to have a single, universal and unanimously agreed definition of the term. However, all educational aspects should have two main objectives; leading out into a new knowledge and experience, and the objective of feeding and thereby growing and developing, (Wijsen et. al., 2006). These two objectives make education a vital process in any human development. Contextually, Wijsen et al hence, view that any form of education should aim at helping human being get the grips of reality, take charge of reality so as to transform it, and accepting the demands of reality by taking responsibility and bearing its hardships. In addition, Bazić (2017) argues that education and its segments are required to transmit adaptive knowledge that shapes new competences required for life and work in specific circumstances.

Within the era of the fourth industrial revolution, Rais (2018) observes that education aims at improving the production efficiency and flexibility through digitization control systems and a

decentralized automation which has partially replaced the labour efficiency of human labour. In light of such understanding of the nature and objectives of education in 4IR, the qualities of a 21st century teacher becomes paramount for a successful shaping of the learner's adaptive basic skills and expertise, knowledge, and attitude. The learning process hence demands to be student-centered as students are required to do activates without being limited, (Purwanto et al., 2023).

According to Purwanto et al. (2023), education in the era of fourth industrial revolution-education 4.0, is a phenomena structure where humans and machines are allied together to solve problems, find solutions and new innovations. Hence, its success and failures can be assessed based on its effects on its users, the learners who are the main consumers, as well as the quality of the 21st century teachers. Hence, education 4.0 should be directed on formation of competent personality with the ultimate aim of improving the quality of human life by solving contextual life needs, and humanizing humans. To actualize this, various national, regional and global policy documents on education have been established with the aim of recommending development of the desired principles and values to be incorporated into the education systems.

With the unveiling of the new curriculum in Kenya based on the Sessional Paper No. 2 of 2015 on '*Reforming Education and Training in Kenya*' and the 2022 Presidential Working Party on Education Reform (PWPER) report on '*Transforming Education, Training and Research for Sustainable Development in Kenya*', the government aims at placing the students at the global market with adaptive capabilities needed for success in the 21st century, (Presidential Working Party on Education Reform, 2023). However, the main question is whether the education industry in Kenya under the new competence-based curriculum is maximumly structured to instill integrative and adaptive value-based skills for the consumers of the existing 4IR. Such discussions should be informed by the fact that within the human capital, creativity, collaboration/teamwork, communication and critical thinking skills can never be automated or replaced.

Moral Education in the Context of Holistic Kenyan Education System

The concept of holistic education has been at the center stage of contemporary education theorists. This has made value-based education systems to receive a lot of attention formally and informally both in local and international face. Rudge (2008) observes that the concept of holistic education has historically been discussed with incorporation of various principles and ideas from; humanistic among others, Rousseau, Maslow, Pestalozzi; progressivists led by Dewey; and social critics among them, Jules Henry, Myles Horton, and Paul Goodman. These theorists view holistic education as a value-based education encompassing worldviews on recognizing divine reality, life interconnectedness and interdependence with internal and external ecosystem world. Hence, holistic value-based education is one that promotes equal rights, empathy, mutual responsibility, caring, love for self/divine, social justice and respect.

In the contemporary global community, the discourse on the call to develop a harmonious, moral, ethical and responsive society has been on the rise. This is informed by the decrease of the value systems among the contemporary generations (Argue and Greenway, 2020). Additionally, the contemporary adolescent's egocentric nature makes them to focus more on their needs instead of looking at circumstances from the point of view of others (Novik, 2018). Hence, Schonrt-Reichl (2011) notes that there has been a burgeoning global attention on the need of empathy construct informed by both; recent historical events related to school bullying and value decrease pointing

to an empathy deficit in today's children and youth; and the rise of the field of positive psychology and youth development into positive human qualities, development of empathy being among them. In Kenyan context, there has been a lot of effort to promote moral education among the learners. This is evident by the establishment of various commissions for example, the Ominde Commission among others, whose main responsibility was to advise the government on the best approach to establish a moral society through responsive education systems. As such, development of religious education as a subject of study within the 8.4.4 system of education was seen as a means to producing a moral, responsible and ethical citizen. However, Makoyo (2022) observes that irrespective of the several policy documents in education that have echoed the need to implement moral education in school, morality and value systems in Kenya has sunk to a record low. This has been despite of the establishment of policy documents as the Gachathi Commision Report of 1976 (GoK, 1976), the Mackay Commision Report of 1981 (GoK, 1981), the Kamunge Commission Report of 1988 (GoK, 1988) and the Professor Douglass Odhiambo Task Force Report of 2010 (GoK, 2010). However, their objectives have not yet wholly been realized. As such, the responsibility of inculcating moral, social and spiritual resilience as well as adaptability in students is partly assumed to be promoted through the teaching of the Christian Religious Education subject along other religious related supportive programmes both in and out of the school environments.

Value-based education model in the Fourth Industrial Revolution Era in Kenya

Kenya is on the forefront trajectory on adopting to the fourth industrial revolution era especially with curriculum change to the Competence Based system of education that partly emphasize digital skills in the learners. The aim of this rationale is to make the 21st century Kenyan students globally competitive, bridge the gender gaps, and prepare learners for the 21st century job market. On a positive trend, the current education system will help to shape the future of the Kenyan learners by conforming to the tenets of the industrial revolution. Here, 21st century pedagogical skills that emphasize value-based skills in digital contexts will help the consumer of education system in Kenya to be holistic in nature.

Various research has been undertaken on value-based education in the context of character and moral development. However, there has been limited research models related to the context of fourth industrial revolution era, and the adaptive value systems and skill development for human competitiveness and relevance. With the characteristic nature of fourth industrial revolution-4IR involving artificial intelligence-AI, virtual interactions, digital channels, machine learning, and biotechnologies, among others, the education industry in Kenya need to design itself with adaptive strategies that will sustain the contemporary and future human capital against the Darwinian principle of the 'survival for the fittest' to avoid elimination and facing out in the local and global realities in social-economic contexts.

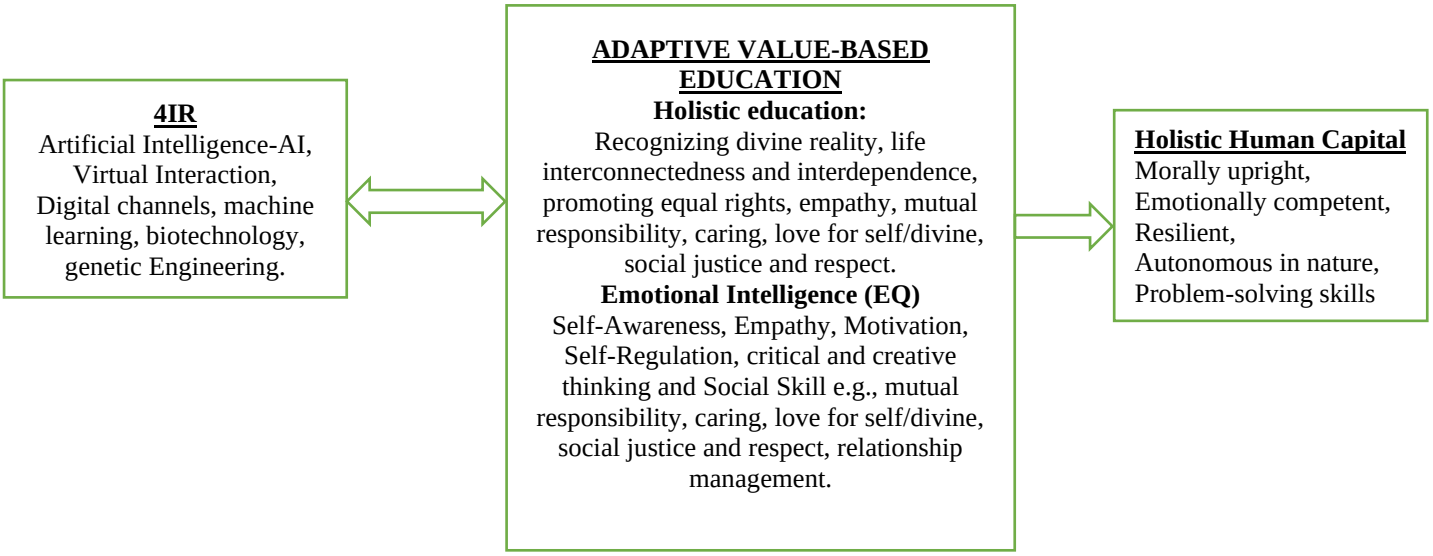
Here, any consumer of modern education systems in the digital industrial world will need holistic education (HE) involving among other aspects like; recognizing interconnectedness and interdependence, divine reality, promoting equal rights, empathy, and mutual responsibility. In addition, social competence characterized by emotional intelligence (EQ) which involves among other aspects like; self-awareness, empathy, motivation, self-regulation, mutual responsibility, caring, social justice, respect and relationship management are/will be vital. This will encourage development of a morally upright, emotionally competent, resilient, autonomous, and a human capital with problem-solving adaptive skills. In view of this, this review paper recommends the

following Value-Based 4IR education model that incorporates both post-modern technological skills alongside social-ethical competences.

In research conducted by the Federation of Kenya Employee (FKE) in collaboration with Africa Digital Media Institute (ADMI), and the Nexford University on the emerging skills needed in the contemporary industrial sectors in Kenya, it was found that the majority of the employers singled out key social skills as a requirement for employability. Among them included; effective communication with 49.1%, critical thinking 41.7%, teamwork 25.7% while other skills identified included empathy, emotional competence among other values (Dianah, 2023). In view of this, this paper found that the within the majority of the research and scholarly work bank in Kenya on value and moral systems, various recommendations on the implementation have been provided. The majority of these research work have highly provided information on the relevance of positive value advancement through the education systems. However, rarely are these recommendations to the government and other education stakeholders actualized. As such, training institutions should utilize these knowledge banks on these value-based research work to inform them on the methodology and value-skill development of the graduates for the future human capital.

With the adoption of Adaptive Value-Based (AVB) 4IR Education Model within education sector, the respective graduates from both basic and technical/professional institutions are guaranteed of employability. While as the graduates are emphasized to equip themselves with the global technological standards in various aspects such as machine learning, digital channels, artificial intelligence among others in production, the adoptive value-based learning will have equipped the potential workforce with the needed holistic aspects and Emotional Intelligence (EQ) and social skills. These include among others; empathy, critical and creative thinking, motivation, self-awareness, self-regulation, among others, recognizing divine reality, life interconnectedness and interdependence, promoting equal rights, empathy, mutual responsibility, caring, love for self/divine, social justice and respect. Adaptive value-based education approach will hence provide the employees with the needed emerging skills in the contemporary industrial sectors in Kenya.

Adaptive Value-Based 4IR Education Model



Such a value-based education model will help the contemporary education theorists and stakeholders to craft and refine education systems to enable learners fit, appreciate, and recognize change in the social-economic global cultural contexts. Also, fourth industrial revolution era will have contextual social benefits as it will help to bridge the global knowledge gap, promote gender inclusivity, promote equitable access to quality education, promote quality knowledge creation and transfer, and will facilitate creation of new professions. For consistency in skill and value development, Kenyan basic and higher learning institutions need an inclusive active curriculum designed to ensure adaptive value-based skills in all fields of formal learning. Emphasis in adaptive valued-based education in the context of fourth industrial revolution era will enable consumers of education systems in Kenya to be more competitive. This is from the fact that a unit change in fourth industrial revolution components demands a change in skill and adaptive value development systems to fit in the global post-modern technological environments.

A well-grounded adaptive value-based education in Kenya, will demand implementation of thematic learning based on scientific learning models which incorporates skills in observation, questioning, experimenting, association, and networking based on Kenyan needs and challenges. However, to achieve this, Taufina and Kharisma (2019) opines that professional teachers must apply the main tasks involved in the thematic learning process which include among others, educating, guiding, training, directing, and assessing students for a meaningful learning. As education system in Kenya unfolds to global trends, the educationists should be partly concerned on the need to produce future human capital who are morally upright, emotionally competent, resilient, who is autonomous in nature, and one with problem-solving skill (Kagema, 2021). Hence, adaptive value-based education will culminate to habits consequential from ethical behaviors, choices, and attitudes possessed by individuals which are informed morals. Possession of social, moral and spiritual competences will help to sustain the consumers of education 4.0 in the fourth industrial revolution era.

From the above model, the success of adaptive value-based education is highly dependent to the competence of the teachers/instructors at the respective levels. As Purwanto et. al. (2023) notes, the success of education 4.0 is determined by the quality of teachers who are constantly required to be adaptable to the emerging challenges and technologies arising from post-modern society. This implies that Kenyan government through the relevant bodies must prepare its human teacher capital with the rising post-modern literacy skills such as emerging technologies, data science literacy, and up to date human literacy. This is because, any form of conservatism in the teaching field, technology is likely to replace the roles of teachers. Investing in human resource should be guided by the fact that investing in human capital can be one of the main assets in a nation's progress.

Challenges and opportunities in education in the era of 4IR

Fourth industrial revolution era has brought with it myriad of challenges to the social contexts, the teacher and the students. Socially, 4IR has brought in new ethical and moral definitions that seem to challenge the existing moral codes of the 21st century society. As such, it has brought a new culture that is expected to alter the way we live, perceive and interact with others hence challenge, change and disrupt every sector of our lives. Consequently, the resulting new social-cultural, moral and spiritual values have introduced to the digital generation new choices and worldviews, philosophies and cultural orientations.

Human beings are social in nature. However, replacing of human labor with machine labor as demanded by 4IR in most of social-economic and cultural spheres, challenges this human character due to reduced human-to-human interactions. In the context of education, it is anticipated that the role of the physical teacher to students in a physical classroom will be reduced and taken over by the interactive virtual machine learning. However, Afrianto (2018) observe that the challenge may not only be the existence of the teacher but also how they will face the new generation who are very close to the gadgets.

Though majority of the countries in Africa are on a high note to implement fourth industrial era in through education contexts. However, the economic status in the majority of the homestead has become the main hinderance from its foundational base. This was tested during the covid-19 phase where acquisition of digital skills place one at a higher rank. During this period, education sector in Africa was highly affected and revealed the nature of digital access and skills in the context of the 4IR where, only less than 10% of the learners for example, in Kenyan schools had access to digital learning process (Ochieng and Ogejo, 2021). In this case, where full structures are not well implemented and actualized, the economically disadvantaged are always at the periphery of the benefits of 4IR leading to marginalization of the latter category in the society.

Though there are myriad of challenges within the era of the fourth industrial revolution, for the optimists, fourth industrial revolution in education sector brings with it a volume of opportunities. Bazić (2017) observes that it has bridged the global gap of knowledge by offering multifunctional mobile network that allows limitless access, knowledge creation and transfer as well as influencing the creation of new profession. Bazić notes that most of today's demanded professions were not in existence in the last 15 years while 65% of learners in the elementary schools today will be working in the professions that are not in existence today. Hence, the future adaptability of the learners to meet the relevance of the future industrial revolutions is vital.

Contemporary social scientists have observed that the fourth industrial revolution will help to bridge the infinitive question of inequality in education acquisition, and gender inequality gap in skill development. Since education 4.0 makes learning process to be limitless, learners can study anywhere and anytime with unrestricted access to new information (Purwanto et. al., 2023). Ultimately, people are/will be judged based on their multiple competence on both technological competence alongside social-ethical competence. This is because, where all learners are maximumly exposed to value-based education, the future human capital will be morally upright, emotionally competent, resilient, autonomous in nature, with problem-solving skills.

Conclusion

The main purpose of this paper was to develop and recommend a value-based education model in the era of the fourth industrial revolution in 21st century societies alongside assessing some of the challenges and opportunities in the education industry in the era of fourth industrial revolution. This review paper appreciates that Kenya as one of the global communities is already in the era of fourth to fifth industrial revolution and its components. Though fourth industrial revolution has socially brought in new ethical and moral definitions alongside new choices, worldviews, philosophies and cultural orientations that seem to challenge the existing moral codes of the 21st century society, new opportunities are brought into place. Among the opportunities are; there has been a bridge to the global knowledge gap, it has promoted gender inclusivity, equitable access to

quality education through digital channels, knowledge creation and transfer, as well as influencing the creation of new professions to the digital generation.

In its contribution, the paper observes that for maximum benefits for the current and future Kenyan human capital, an adaptive value-based education orientations characterized by multiple intelligence combined in both post-modern technological skills alongside social-moral and ethical competences is vital. Hence, an adaptive value-based 21st century education model is recommended. It is only in this approach, that Kenyan education system in the context of 4IR will be relevant in improving production efficiency and effectiveness in various industries.

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Project Based Training as a Strategy for Equipping Z-Generation Work Force with Transferable Agricultural Competencies

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Abstract

The Z-generation is being trained at a time when the world is undergoing global challenges in agriculture. These challenges call for global concerted solutions where education takes the center stage. Thus, pedagogical approaches to equip trainees with problem-solving competencies cannot be undoubtedly estimated within the educational sphere. Project Based Learning (PBL) has been found to equip trainees with 21st century skills for problem solving. The paper documents the findings from a tracer study conducted in 87 secondary schools across Egerton three Teaching Practice zones, spanning a period of 10 years. Evidently, the findings reveal onsite success cases of PBL by Agricultural Education and Extension (AGED) undergraduate students where a total number of 125 Agriculture Teaching Practice Projects (ATPPs) were traced with 36 % of them being still in existence. Of these, livestock production emerged as the most common type of project with 34.5% while farm structures accounted for 19.6% of all the projects that were still in existence. Over time, most of the livestock production structures done as ATPPs had either been transformed into other structures or demolished due to competition for space. Transferability was measured on three fronts namely the application of Project Based Training (PBT) after graduation, use of the ATTPs in teaching other subjects and application of the PBT in establishing teaching learning projects by the AGED graduates in their stations. From the findings, it was concluded that less than half of the ATTPs established were still in existence and in use by over 87% of the teachers. Transferability of PBT existed either in teaching other subjects, establishing new agriculture teaching projects in schools or teaching agriculture subject. The study recommends that training institutions need to deliberately repump the PBT for acquisition of transferable skills necessary in solving global challenges.

Key Words: Agricultural Teaching Practice Projects, Global challenges, Problem solving, Project Based Training, Zoomers generation.

Introduction

The second Sustainable Development Goal (SDG) by the United Nations is on Zero hunger geared towards ending hunger, achieve food security, improved nutrition and promote sustainable agriculture (United Nations, 2017). Agriculture being the economic mainstay of the country (Kathula, 2023). Agricultures vibrant future is fested on the hands of the youth, the Z-generation (Widagda et al., 2022). The z-generation comprises 26% of the total population in the globe with over two Billion people. This population is more than one quarter of the entire world population and their potential to influence the economic sphere of the nation's cannot be downplayed. This is a youthful generation that is digitally native and has all its activities and investment in the digital space (Mathur & Hameed, 2016). However, agricultural production to address food security issues

may not necessarily be done in that digital space. Therefore, training this generation in readiness to this gigantic task is inevitable. Equipping the Z-generation with the 21st century competencies to solve global challenges that need globally concerted efforts in manifest (González-salamanca et al., 2020; (Mawonde & Togo, 2019)

Pedagogical approaches to train this generation on agricultural competencies for posterity come in handy. Participatory training of the 21st century youth require properly thought-out learning experiences, resources and appropriate pedagogy (Macarthur, Catherine T, 2021). Among the transformative pedagogical approaches are problem-based learning, simulated classrooms, cooperative learning, experiential learning and project-based learning (Mawonde & Togo, 2019). Although some of these methods have been in existence for a long time, repackaging the approach and trainers' zeal to embrace hands on experiences in training of agriculture cannot be overemphasized. According to (Gallagher & Savage, 2023) Project-Based Training (PBT) also referred to as Challenge-Based Training gives the trainees an opportunity to practice, be innovative, promotes critical thinking and implementation of their new ideas and technological advancements. Through projects, trainees in agriculture are able to try new innovations, expand existing projects, tailor projects that are entrepreneurial oriented and through technology; projects that embrace technology in Artificial Intelligence (AI), mechanization, value addition as well as marketing.

The Objectives of the Study

The study aimed at tracing the success of Project Based Training as a strategy for preparing the Zenenial/Zoomer generation for the agricultural world of work.

Research Questions

i. What types of agriculture projects that existed in schools initiated by AGED teacher trainees from Egerton University?
ii. What is the utility of the ATPPs established by AGED teacher trainees from Egerton University in the host schools?

Scope of the Study

This study focused on the teachers of agriculture in the schools where student teachers of Agricultural education did teaching practice between 2011 and 2020, from three selected teaching Practice Zones. It also focused on ATPPs in existence and established by AGED students on teaching practice.

METHODOLOGY

Sampling Procedure and Sample Size

A total of 432 Egerton University AGED graduates between 2011 and 2020 were traced through snowball sampling. From this number across the ten teaching practice zones, a minimum sample of 125 projects was targeted from the three zones that recorded the highest responses in the baseline survey. Onsite visits captured 134 projects and after data cleaning a total of 127 ATPPs were used to present the findings. The three TP zones visited were Kericho-Bomet Kisii, Eldoret-Kitale and

Kisumu-Siaya –Busia-Kakamega. Across the visited schools, a total of 64 teacher of agriculture who are Alumni of Egerton were interviewed on usability of the ATPs.

Data collection Methods

A checklist was used to trace the quality of the existing ATPPs while an interview schedule was used to establish the usability of the existing projects in the host stations. These instruments were developed by the researchers. The structured instruments contained both open ended and closed ended items. They were developed based on the objectives of the study. The questionnaire had two sections with section A sought the respondents' demographic data and section B sought to determine the ways of utilizing the teaching practice projects established by AGED students in their TP schools.

Data Analysis

Data obtained were cleaned, checked for accuracy and completeness, and thereafter, analyzed. Descriptive statistics were generated as per the objectives of the survey. The findings were presented in figures (graphs and charts) and tables. Additionally, qualitative data was summarized and described using frequencies and percentages.

RESULTS

Existence of ATPPS in Host Schools

Determination of whether the ATPPS were actually in existence or not was core in this study. Table 1 indicates a summary of the ATTPs established by AGED graduates during the study period. A total of 125 ATPPs were accessed and subjected to a checklist with a view to determining their status and use. The projects traced were categorized according to type and the distribution is as presented in Table 1.

Table 1

Breakdown of Projects type per type

Project Type	Frequency	Percentage (%)
Livestock production	37	29.14
Farm structures	33	25.99
Crop production	19	14.95
Other	12	9.45
Weed and Weed control	12	9.45
Soil and water conservation	7	5.51
Fish farming	3	2.36
Agricultural Economics	1	0.79
Agroforestry	1	0.79
Apiculture	1	0.79
Factors influence agriculture	1	0.79
Grand Total	**127**	**100**

The findings from phase this phase were congruent with those of phase one where majority of the projects traced in schools were related to livestock production and farm structures at 29% and 26% respectively. Other areas where students on TP established projects in larger numbers were: crop production, weed and weed control and soil and water conservation at 15%, 9% and 5% respectively.

Out of the 127 ATPPs traced, 47 (37%) of them were still in existence by the time of data collection in May 2023. These existing projects were further analyzed and categorized according to project type and the findings were as presented in table 2.

Table 2

ATPPS still in Existence in Schools

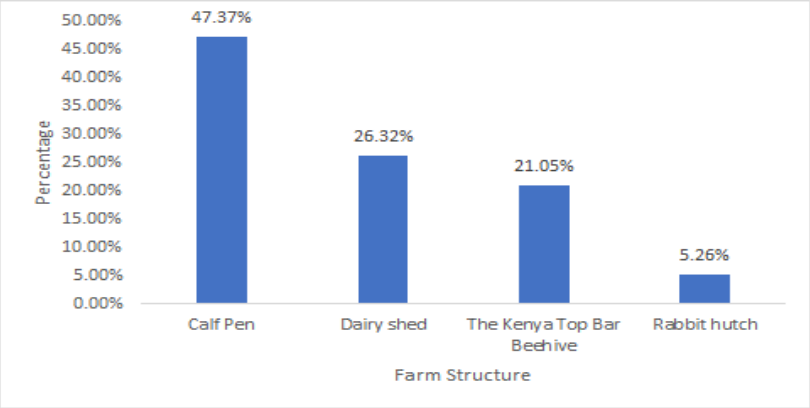
Project Type	**Frequency**	**Percentage**
Farm structures	19	40.43
Livestock Production	15	31.92
Weeds and weed Control	6	12.77
Other	3	6.38
Soil and soil fertility	2	4.26
Apiculture	1	2.13
Horticultural crops production	1	2.13
Grand Total	**47**	**100**

Although more livestock production projects were traced as per Table 1, there were fewer projects that were still in existence and hence more of the farm structures still existed in schools even in cases where schools had stopped rearing the related livestock. During this tracer study, it was clear that schools would be more willing to maintain and sustain projects that complemented their development plans. For instance, schools interested in rearing livestock for milk or meat production were more likely to maintain livestock related production process and farm structures because they were relevant and financially meaningful to them. Thus, students initiating projects during TP need to link up with the school administration or farm managers or the subject teachers in understanding their future plans especially in the entrepreneurial lens.

Further analysis was done on the existing farm structures in schools to understand the most prevalent type of farm structure and the results were as shown in Figure 1.

Figure 1

Distribution of types of farm structures (n=19)



Calf pens were the most common farm structures established by students at 47% followed by dairy shed at 26%, construction of Kenya Top bar Hive at 21% and lastly a rabbit hutch at 1%. It is critical to note that students on TP are meant to teach Forms One and Two but for project establishment they can establish a project across the agriculture curriculum. Farm structure is a topic covered in Form Three and referred to, in other topics covered in Form three and four including Livestock production IV (Livestock rearing practices), Livestock Production VI (Cattle Production) and Livestock Production V (Poultry). The broad scope covering farm structures in the curriculum may explain why most students choose farm structures as their projects during TP and the fact that they can exist even when no livestock is being reared by the school.

The livestock production projects established as ATPPs were further analyzed and the results presented in table 3 indicate that Rabbit and Poultry production were the most common at 33% and 26% respectively. This could be explained by the fact that rabbits and poultry are small animals that require little space for shelter, are light feeders and easy to manage and hence are affordable for students on TP to raise as part of their ATPPs. From these findings, it is clear that the more the investment needed to raise a given livestock, the less favorable it becomes among the students on TP.

Table 3

Categories of livestock production projects established by students on TP

Livestock Production	**Frequency**	**Percentage (%)**
Rabbit hutch	5	33.33
Poultry production	4	26.67
Livestock breeds album	3	20
Fish pond	1	6.67
The Kenya Top Bar Beehive	1	6.67
Pig production	1	6.67
Total	**15**	**100**

The status of the existing ATPPS was established guided by certain parameters which were measured on a Likert scale the findings were as presented here in table 4: All the existing ATPPs had a mean of above average for all identified indicators to measure their status except for identity. This implies that most of the projects were under good maintenance by the schools through the concerned teachers of Agriculture.

Table 4

Summary analysis of ratings of the parameters

Status Indicators	N	Mean	Mode	Median	Lower	High
Quality	47	3.83	4	4	1	5
Originality	47	4.06	4	4	1	5
Innovation	47	4.06	4	4	1	5
Creativity	47	3.98	4	4	1	5
Condition	47	4	4	4	1	5
Relevance	47	4.68	5	5	1	5
Connivence	47	4.19	4	4	1	5
Accessibility	47	4.28	4	4	1	5
Identity	47	2.13	1	2	1	5
Storage	47	3.85	4	4	1	5
Maintenance	47	3.32	4	4	1	5

The high mean of the indicators of the status of the existing projects is a clear pointer that institutions were willing to safeguard and sustain ATPPs that they attached value to. Teacher trainees seeking to initiate ATPPs in schools need to gather information of their future plans so that good will towards managing and sustaining the established projects is guaranteed. Besides the 47 ATPPs in existence some stood out in different schools. These cases present the power of PBL which empowers trainees to transform their society by establishing projects that have long term impact to the institutions.

CASE ONE:
A bamboo stools established in one of the schools had helped reclaim the school land that faced erosion due to high water levels whenever the region experienced high rainfall. The Bamboo thicket helped change the course of the stream that was widening at a faster rate than the institution was prepared for. As a result, this project has helped the school to sell Bamboo for income, reclaim their waste land and recover land near a water source which the school uses to grow vegetables and arrow roots supplementing the school feeding project.

Plate 1: Bamboo Forest established as a remedy to land wasting

CASE TWO:

A teacher trainee established a Cypress and Eucalyptus woodlot within the school in one of the areas regarded as dry. Sharing with the School Principal, he revealed the multiple benefits that ATPPs had brough to the school for years. The success of the woodlot motivated the school principal to transform the whole school compound into an evergreen environment. Those trees provide shade to students studying under them as the region uses the tropical timetable mode. The trees which area variety, make the environment very appealing and conducive for learning. Above all, the woodlot had provided timber which helped roof a block of four classrooms. The amount of money the school saved out of the project initiated by the student on teaching practice in the school was a land mark the school has recorded in their history books. They have also replenished the woodlot and expanded it around the classes providing a barrier to very strong winds that are very prone to the locality.

Plate 2a : Students reading under the trees

Plate b: Wood lots established behind the block of classes

Case Three:

A piggery project initiated in one of the host schools was a motivating factor for the school to expand the project form two pigs to a population of over 40. The large litter farrowed by the initial stock encouraged the school to expand the breeding stock and within six months, the project provided pork to students cutting on the cost of meat while taking care of the nutrition of the learners. In addition, management of food waste from the kitchen and dining hall became cheaper

as the pigs would feed on all the left offers reducing the cost of production. Motivated by the outcome the school expanded to poultry and dairy production. The manure obtained was channeled to the school farm improving on vegetable and crop production supplementing the feeding program with organically produced food that a has a wealth of benefits to their health.

Plate 3a: Poultry project

Plate 3b: Dairy project

The sampled success cases present the opportunities in using PBT as a strategy in training the Z-generation in preparing them for the world of work. It equips the trainees with multiple competencies critical in solving cross cutting challenges. The solutions provided are also multi-dimension with clustered benefits to multiple stakeholders. In this context, all the cases provided did not just the trainees in learning neither the teachers in using the projects as resources but they were of benefit to the teachers in other subject areas, school administration, parents, support staff, the community around the school among other indirect stakeholders. These multi-dimensional benefits of a solution to an identified problem cannot be underestimated especially in the 21st century when the emerging challenges have a dynamic orientation.

To establish these projects in schools, the trainees need the skill of communication to express themselves in consulting on the gaps to be addressed and also in writing a proposal for the project. They also need problem solving skills to be able to identify a problem within the school and provide a possible solution. They also need critical thinking skills to allow them provide a long term solution. Innovativeness is critical since they should provide a solution that is not only original but also that is broad-based to multiple problems. Collaborative skills are essential in project-based learning because success of the project initiated is anchored on how the trainee interacts with those who have a role in the project planning, execution, evaluation and monitoring. These are the transferrable skills that every 21st century trainer should champion when training the Z-generation for the opportunities in the agriculture related space.

Agriculture Teaching Practice Projects Existence

A total of 67 teachers of Agriculture who were graduates of AGED were also traced and the aspect usability of ATPPs determined. The distribution of the teachers by gender was 57% to 43% males to females respectively. When asked on whether there were existing ATPPs established by Egerton University students in their school, 81% indicated Yes while 19% indicated No as presented in the figure herein. These projects present a long-term opportunity for use and reuse of teaching resources in a school within the subject and across other related subjects promoting integration of knowledge which is a pillar promoting competency-based training. Further, the 80% of those who

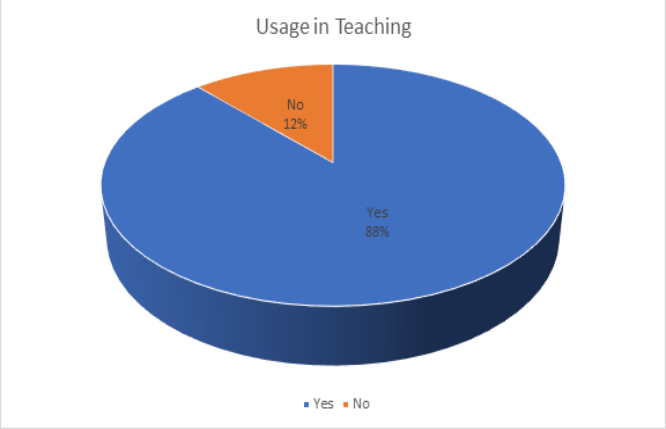
found the agriculture projects by the Egerton AGED students were further asked whether they all existed 44% indicated yes while 47% indicated that only some were still in existence. The findings indicate the need to enhance sustainability mechanism for the ATTPs.

Utilization of Agriculture Teaching Practice Projects (ATPPs) in Teaching by the teachers traced onsite

The over 50% respondents who indicated to have found existing ATPPs in their stations were further asked if they utilized them in teaching. The response towards use was overwhelming with 88% indicating to have utilized them in teaching. The high utilization percentage implying that the ATPPs were still relevant and utilizable as teaching resources in secondary schools. It also indicates a high level of engagement and recognition of the value that these projects bring to the learning environment. The ATPPs serve as valuable teaching resources that contribute to enhancing the learning experience and delivering quality agricultural education.

Figure 2

Use of existing ATTP by teachers



Asked the topics they taught most using the already existing ATPPs, majority of the respondents indicated to have taught the topics on livestock production and farm structures. This is so, given that the two categories presented most of the already existing projects in schools as presented by the data from the checklist.

Further, asked on the frequency of use of the ATPPs by other teachers, the findings indicated that 40% use by both Biology and Geography teachers while the frequency of use by other subjects was negligible. This indicates that ATPPs have been utilized to enhance biology education, potentially focusing on topics such as agricultural biotechnology, ecosystems, or the interconnections between agriculture and biological systems. Additionally, the use of these projects in teaching Geography subject demonstrates the interrelatedness and integration of knowledge and skills that promote holistic training of the Z-generation.

Conclusions

From the findings, it is clear that ddifferent types of ATPPs existed in schools initiated by AGED teacher trainees from Egerton University mostly from livestock production and farm structures pointing towards durability and the entrepreneurial perspective in the projects established in schools. Additionally, the ATPPs established by AGED teacher trainees from Egerton University in the host schools were utilized as teaching resources within and cross subjects, others were used to generate income, supplement school feeding programme, aesthetic value while others enhanced land reclamation; a pointer to multiplicity of use of projects.

Recommendations

This paper recommends that students on teaching practice need to be sensitized to initiate projects that are long term in schools and those aligning with the schools' blue print. The trainers of Agriculture too need to explore the multiplicity in utilization of the ATPPs established in their schools for maximum use of such projects in training the Z-generation and exposing them to the opportunities that exist in Project Based Learning.

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Correlation between Entrepreneurship Education and Students' Entrepreneurial Intentions: A Case of the University of Dar es Salaam, Tanzania

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Abstract

Tanzania's government has instituted measures to foster entrepreneurship training and business initiatives, such as the National Entrepreneurship Training Framework. Despite attempts to instill entrepreneurial skills at the university level, there has been a decline in self-employment among graduates. This research aimed to explore the connection between university-level entrepreneurship education and the entrepreneurial intentions of student-teachers at the University of Dar es Salaam. Utilizing correlation research methodology, the study took place at the University of Dar es Salaam, which comprises various colleges, schools, institutes, and centers. The chosen UDSM includes two constituent colleges, seven on-campus colleges, seven schools, seven institutes, and thirteen centers. Entrepreneurship education primarily occurs at UDSM through UDBS, with coordination in SOED for Bachelor of Education in Commerce student-teachers. Simple random sampling, involving 36 respondents from each target population, was employed for probability sampling. The findings revealed no statistically significant association between university entrepreneurship education and entrepreneurial intentions among student-teachers at the University of Dar es Salaam. The null hypothesis was accepted due to the absence of a statistically significant correlation between studying university entrepreneurship education and possessing high entrepreneurial intentions among student-teachers at the School of Education, University of Dar es Salaam Mwalimu Julius Nyerere Mlimani campus. These results warrant further exploration of the study's focus to attain a definitive and undeniable perspective. Future research should delve into the reasons behind the statistically significant correlation between university entrepreneurship education and entrepreneurial intentions among student-teachers at SOED in UDSM, examining both undergraduate and post-graduate levels at SOED.

Key words: Entrepreneurship education, Entrepreneurial intentions, General enterprising tendency, Higher education, Tanzania

1.0 Introduction

Entrepreneurship education has drawn unprecedented attention among policymakers, scholars' and higher learning institutions (HLIs). The attention is mainly due to efforts that are made to ensure education is made relevant by producing graduates who are either unquestionably employable or those who are capable of creating their own employment. For the latter, entrepreneurship knowledge is taken to be the way out. In line with such outlook, literature has shown that lack of business skills is one of the factors preventing Tanzanian university graduates from starting their own businesses (Ntare & Ojwang, 2021) despite the fact that universities are meant to provide entrepreneurship education that can help recipients to start their own businesses (Amos & Alek, 2014). It can therefore be anticipated that university students develop interest in creating entrepreneurial business particularly after graduating, hence their intentions to do so.

As assumed in Icek Ajzen's theory of planned behaviour, intentions are the result of three antecedents: attitude change, social norms and perceived behaviour control. University entrepreneurship education is intended to foster positive attitude toward entrepreneurship, to assist recipients in overcoming negative subjective norms that may interfere with their entrepreneurial journey and view entrepreneurship as a simple rather than difficult task to complete (Mangasini, 2015).

Despite the fact that entrepreneurship education is available up to the university level, unemployment remains a problem in many countries. For instance, in Canada, as of 2020, unemployment among those with a tertiary education aged 25-64 was 6.7% (OECD, 2022). Unemployment is also prevalent among the well-educated in the Kingdom of Saudi Arabia (Harvard Kennedy School, 2018) despite the fact that higher education institutions in the kingdom work very hard to develop graduates with skills in entrepreneurship and innovation (AlSharie & El-Gohary, 2016). In Chile, recipients of entrepreneurship education have no greater likelihood of becoming entrepreneurs than non-recipients (Pobleto & Amoros, 2013). Similarly, 13.0% of South African tertiary education graduates aged 25-64 were unemployed in 2020, which is higher than the OECD rate of 4.6% and the G-20 rate of 4.8% (OECD, 2022).

In Tanzania, despite efforts to teach entrepreneurship at the university level, graduates' self-employment is on the decline trend (Mwasalwiba et al., 2012). Across years, the central government of the United Republic of Tanzania enacted policies to promote entrepreneurship training and business venture among Tanzanian citizens and residents (Kalimasi, 2018). The National Entrepreneurship Training Framework is a good example of such policy. Despite the aforementioned policy and entrepreneurship education being offered by universities in the country, entrepreneurship venturing of recipients remains low, owing to Tanzania's high levels of graduate unemployment (Ntare & Ojwang, 2021).

Since the country's independence, youth unemployment has been a major concern (Kiaga, 2016; Ntare & Ojwang, 2021). Every year, approximately 900,000 young Tanzanians enter the labour market, though there is creation of 50,000 to 60,000 jobs annually (Mwita, 2019; Ntare & Ojwang, 2021). Thus, the majority of graduates remain unemployed (Ntare & Ojwang, 2021). In response, it is claimed that increasing entrepreneurial education is an important way to combat the unemployment problem (Mangasini, 2015). It is against this background that this study was undertaken to establish the link between university entrepreneurship education and entrepreneurial intentions among student-teachers at the University of Dar es Salaam. Developing entrepreneurial education is an important solution to unemployment (Mangasini, 2015). The study's major hypothesis was that there was no correlation between university entrepreneurship education and high entrepreneurial intentions. This is because there was conflicting empirical literatureof both developed and developing countries as evidenced in the literature review section of this study.

1.1 Hypotheses of the Study

1. There is no correlation between university entrepreneurial education and entrepreneurial intentions of year one student-teachers at SOED, in UDSM, Tanzania.
2. There is no correlation between university entrepreneurial education and entrepreneurial intentions of year two student-teachers at SOED, in UDSM, Tanzania.

3. There is no correlation between university entrepreneurial education and entrepreneurial intentions of year three student-teachers at SOED, in UDSM, Tanzania.
4. There is no correlation between university entrepreneurial education and entrepreneurial intentions of university students at SOED, in UDSM, Tanzania.
5.

2.0 Literature Review

2.1 Relationship between Entrepreneurship Education and Entrepreneurial Intentions

Duong's findings in 2021 suggest that entrepreneurship education, while not directly influencing entrepreneurial intentions, can enhance these intentions by shaping students' attitudes towards entrepreneurship and their perceived control over their behaviour. Liu et al. (2020) argue that the effectiveness of entrepreneurship education in promoting students' entrepreneurial inclinations hinges on the quality of the learning environment for entrepreneurship education. In line with this, Possaro et al. (2018) propose that university-based entrepreneurship education is more likely to foster entrepreneurial intentions when it includes hands-on, practice-oriented entrepreneurial courses.

Boahemaah et al. (2020) contend that entrepreneurship education can effectively equip undergraduate students with the skills and knowledge needed for entrepreneurial endeavours, as it directly contributes to a positive impact on their entrepreneurial intentions. Hattab (2014) supports the idea that exposure to courses like marketing, accounting, and management can effectively teach entrepreneurship by providing students with valuable knowledge and practical skills for launching and growing businesses. Additionally, Dickson et al. (2008), as cited by Hattab (2014), assert that entrepreneurship education positively reinforces students' attitudes toward pursuing entrepreneurial careers, especially in developing countries.

Afriyie and Boohene (2014) find that entrepreneurship education substantially enhances university students' ability to initiate their businesses, steering them away from seeking salaried employment, as there exists a positive association between entrepreneurship education and an orientation toward entrepreneurship.

Duong's 2021 study indicates that entrepreneurship education significantly contributes to the development of entrepreneurial intentions among students majoring in economics and business management. Enrolling in business management fields is thus considered a means to acquire the requisite entrepreneurship knowledge and skills. Liu et al. (2020) stress that a positive relationship between entrepreneurial tendencies and entrepreneurship education exists regardless of gender.

Sun et al. (2017) discovered that the effectiveness of entrepreneurship education in nurturing entrepreneurial intentions lies in its capacity to teach not only the "what" of entrepreneurship but also the "why" and "who" of the entrepreneurial journey. Israr and Saleem (2018) highlight a strong and positive correlation between entrepreneurial education and entrepreneurial intentions, suggesting that universities should prioritize attracting students to entrepreneurship education.

Barba et al. (2018) emphasize the influence of formal learning from entrepreneurship courses on

shaping entrepreneurial intentions. They recommend conveying the message that entrepreneurship training should be about learning, creating, solving, and taking proactive action. Kadir et al. (2012) assert that purposeful entrepreneurship education can heighten students' entrepreneurial intentions by improving their attitudes, knowledge, and skills. They further note that formal entrepreneurship education provides students with valuable experiences, role models, social encouragement, and support through practical activities, business plan development, and running real or simulated small businesses.

Kadir et al. (2012) argue that student participation in entrepreneurship training programs leads to changes in attitudes and intentions, and exposure to proper entrepreneurship education fosters a positive perception of entrepreneurship as a viable career choice. Dogan (2015) identifies a significant positive relationship between entrepreneurship education and entrepreneurial intentions, highlighting the substantial impact of entrepreneurship education on these intentions.

2.2 Disputed Relationship between Entrepreneurship Education and Entrepreneurial Intentions

Ceresia (2018) contends that the entrepreneurial intentions exhibited by individuals after undergoing entrepreneurship education primarily stem from their pre-education entrepreneurial intentions, rather than being a direct result of the entrepreneurship education course itself. Pre-educational entrepreneurial intentions exert a statistically significant influence on post-educational entrepreneurial intentions, whereas the impact of entrepreneurship education on post-educational entrepreneurial intentions is not statistically significant. When we account for pre-education entrepreneurial intentions, the slight and positive relationship between entrepreneurship education and post-education entrepreneurial intention effectively becomes negligible.
Oosterbeek et al. (2010) asserts that entrepreneurship education is falling short of achieving the intended effect in shaping entrepreneurial intentions. This is because students gain a more realistic understanding of the challenges associated with entrepreneurship and the demands it places on individuals. Therefore, entrepreneurship education fails to produce the desired impact on the formation of entrepreneurial intentions.

Amos and Alex (2014) argue that factors such as job security and workload negatively affect students' entrepreneurial intentions. Due to the uncertainties in entrepreneurship and their pursuit of self-actualization, university students are more inclined to seek formal employment rather than entrepreneurship. Students exposed to entrepreneurship education in their final year of study have limited exposure to entrepreneurship and, consequently, exhibit lower entrepreneurial intentions. In developing countries, students often fear that a failed business venture could make it challenging to secure new employment in the government or private sector, thus leading them to prefer formal sector employment.

Bae et al. (2014) emphasizes that there are theoretical and empirical disagreements regarding the relationship between entrepreneurship education and entrepreneurial intentions. They argue that the commonly observed association between entrepreneurship education and entrepreneurial intentions is likely due to a selection effect, both theoretically and practically. Irrespective of the duration or format of entrepreneurship education, there is no significant impact on the relationship between entrepreneurship education and entrepreneurial intentions. Individual differences among entrepreneurship education students, as well as variations in the format of entrepreneurship

education (e.g., semester-based or workshop-based), do not significantly affect this relationship. Despite additional research, theoretical and empirical disagreements persist.

According to Kalimasi (2014), entrepreneurship education is not well integrated into university curricula and is not tailored to enhance skills applicable to various forms of employment. Hussain and Norashidah (2015) found mixed results in empirical research regarding the influence of entrepreneurship education on entrepreneurial intention formation.

Nabi et al. (2018) suggest that entrepreneurship education does not directly increase students' entrepreneurial intentions; instead, it imparts knowledge about entrepreneurship. Entrepreneurship education can have conflicting effects on entrepreneurial intentions, particularly among first-year college students. It can either increase or decrease these intentions. Understanding the theoretical and practical aspects of entrepreneurship can lead to a theoretical comprehension of venture creation. Subsequently, many recipients of entrepreneurship education become aware of the challenges within the field and lose interest in entrepreneurship, opting for less risky career paths. Negative experiences with teaching methods or instructors can diminish the entrepreneurial intentions of some entrepreneurship education recipients. Several factors, including age, nationality, family support, and commitment to entrepreneurship, can cause significant variations in entrepreneurial intentions among first-year students. External barriers such as financial planning and access to bank loans also play a pivotal role in determining entrepreneurial intentions among entrepreneurship education recipients. The relationship between entrepreneurial education and entrepreneurial intentions can be both positive and negative, making it challenging to design a one-size-fits-all entrepreneurship education program that universally boosts students' entrepreneurial intentions.

Ceresia (2018) concludes that pre-educational entrepreneurial intentions heavily influence post-educational entrepreneurial intentions, while entrepreneurship education does not exert a direct influence on these intentions. Many scholars remain sceptical of the link between entrepreneurship education and entrepreneurial intentions, as engaging in entrepreneurial activities necessitates complex entrepreneurial decision-making that can be influenced by various other factors (Passaro et al., 2018).

3.0 Methodology

3.1 Design

This study employed the correlation research design. This study used correlation research design to answer the main research question andsubsidiary questions. Many studies in education are concerned with establishing relationships between variables (Cohen et al., 2018). The type of correlation ofcoefficient that was used in this study was Point Biserial correlation. Mathematically, point Biserial correlation coefficient is calculated just as Pearson bivariatecorrelation coefficient is calculated. In answering contributory questions, descriptive research design was used.

3.2 Population and Sampling

The study was undertaken at the University of Dar es Salaam. According to TCU (2022), Tanzania had 47 registered universities and university colleges as of July 2021. The selected UDSM is constituted by two constituent colleges, seven on campus colleges, seven schools, seven institutes, and thirteen centres. The research was carried out at UDSM because the first entrepreneurship course in Tanzania was offered by this University in the year 2000. (Fulgence, 2015). According

to Mangasini (2015), entrepreneurship education is primarily taught at UDSM through UDBS. In SOED, there are units that are taught to student-teachers in coordination with UDBS. These units are taught to Bachelor of Education in Commerce student-teachers at SOED.

In this study, simple random sampling was used for probability sampling. Six respondents were chosen from each target population, for a total of twelve respondents per subsidiary question. There were 36 respondents in the study because there were three subsidiary questions. According to Ary (2014) Critical Values of the Pearson Product Moment Correlation Coefficient, a minimum of 5 samples were required at the 0.05 level of significance two tailed. This means that the minimum requirement was met for each subsidiary question because the researcher increased the minimum requirement by 2.4, resulting in 12 samples for each subsidiary question. A minimum of 13 samples are required to detect a correlation coefficient of 0.81 with a power of 95% using the G-Power sample size calculator for two tailed point Biserial correlation. The research was carried out at UDSM because the first entrepreneurship course in Tanzania was offered by this University in the year 2000. (Fulgence, 2015).

3.3 Instruments

The questionnaire was administered directly by the researchers. A directly administered questionnaire is given to a group of people who have gathered in a specific location for a specific purpose (Ary et al., 2014). The dependent variable was captured using GET2, which was adapted from Caird (2013) but translated to Swahili using Google Translate to reduce the impact of language barriers on the study's results. According to Aiken (2019), Google Translate from Swahili to English has a BLEU 3 score of 70% in terms of accuracy. Concerning the independent variable, the researcher obtained entrepreneurship education teaching from the Office of the Director of Undergraduate Studies, who confirmed that the constructs used by the researcher to indicate the presence of university entrepreneurial education were 100% applicable among UDSM student-teachers.

3.4 Validity and reliability

Caird's (2013) General Enterprising Tendency Test has both content and face validity (Mangasini, 2015). The test has criterion validity and can distinguish significant differences between different students' entrepreneurial tendencies, implying that the instrument has good validity (Mangasini, 2015). To ensure the external validity of the research findings, the researcher did not generalize the research findings beyond the capacity that the sample size permitted. According to Liu et al. (2019), previous entrepreneurship studies such as those by Johnson and Fan Ma (1995), Cromie and Callaghan (1997), Stormer et al. (1999), Cromie (2000), Wise et al. (2003), Henry et al. (2004), Kirby (2004), Bulsara et al. (2010), Ismail (2010), Nasrudin and Othman (2012), Zahari et al (2018). This popularity may be attributed to the fact that the tests are regarded as comprehensive, accessible, easy to administer, and simple to score, as well as having been thoroughly tested and found to be both reliable and internally consistent (Liu et al., 2019).

3.5 Statistical Treatment of Data

Data was treated through the Pearson Product moment correlational coefficient using the Statistical Package for Social Sciences.

3.6 Ethical considerations

Ethics is based on the contrast between what is good and terrible, right and wrong. Ethical research is concerned with what researchers should and should not do in their research, as well as how their research should be conducted (Cohen et al., 2018). The below mentioned were observed during this study: The researcher did not coerce or deceive the respondents into participating in the study, but instead informed them about it. The researcher included the accessible population in the study who accepted to engage in the investigation in this study. The researcher honoured respondents' rights to withdraw at any time, not complete specific items in the data collection tools, or not return the data collection tools supplied to them by the researcher. The researcher accomplished this by not coercing or bribing respondents to change their minds, by not being disappointed by any of the respondents' acts, and by not attempting to persuade them to change their minds. The researcher did not share the information provided by respondents in this study with third parties who were not required to receive it. This was achieved by the researcher doing data analysis without the involvement of any third party and by ensuring that raw data was always encrypted.

3.7 Data processing and strategies

As for data processing, Caird's (2013) proposed tools were used to process entrepreneurial intentions. SPSS was used to process data for this study's main and subsidiary questions, as well as the second and third contributory questions. The first contributory question of this study was processed using content analysis, as proposed by Calderon (1993). Data interpretation for high entrepreneurial intentions was performed using Caird (2013) criteria, and data interpretation for the strength and direction of correlation was performed using Cohen et al (2018) and Ary et al (2018) criteria (2014).

4.0 Findings and Discussions

This section presents findings and discussions of the research. The section was guided by the following research question: Is there significant relationship between entrepreneurship education and students' intention to become entrepreneurs?

This research question called for testing of the following hypothesis: there is no significant relationship between entrepreneurship education and students' intention to become entrepreneurs. The null hypotheses were tested through Pearson Correlations Statistical tool as appears in table 1 to table 4.

4.1 Year One Results

The study intended to establish the correlation between entrepreneurship education and entrepreneurial intentions among 1st year students as appears in table 1. As the Table 1 shows, the p-value was greater than the critical value (0.05) and therefore the null hypothesis was rejected.

Table 1

Correlation between 1st year students' entrepreneurship education and entrepreneurial intention

Correlations

		University Entrepreneurship Education	Entrepreneurial Intentions
University Entrepreneurship Education	Pearson Correlation	1	-.109
	Sig. (2-tailed)		.736
	N	12	12
EntrepreneurialIntentions	Pearson Correlation	-.109	1
	Sig. (2-tailed)	.736	
	N	12	12

Source: Field Data (2023)

There was no significant relationship between university entrepreneurship education and entrepreneurial intentions among first year target population of this study, r_{pb} (10)= -.109, p=0.736. Null hypothesis 1 was accepted because point biserial correlation = -0.19, P value (0.736) is greater than Alpha value of the study (0.05) asillustrated in Table 1. The observed point Biserial correlation (-0.19) is less than +or – 0.5760 and thus the correlation obtained in this study was not statistically significant at .05 level. This means that this observed correlation coefficient is not as a result of chance in a population where the true correlation in the population is zero. The findings of the study differ from those of Dogan (2015) which discovered a significant positive correlation between entrepreneurship education and entrepreneurial intentions.

Thus, we maintain that there is no significant relationship between entrepreneurship education and first year students' intention to become entrepreneurs.

4.2 Year Two Results

The study intended to establish the correlation between entrepreneurship education and entrepreneurial intentions among 2nd year students as appears in Table 2. As the table shows, the p-value is greater than the critical value (0.05) and therefore the null hypothesis was rejected.

Table 2:

Correlation between 2nd year students' entrepreneurship education and entrepreneurial intention
Correlations

		University EntrepreneurshipEducation	Entrepreneurial Intentions
University EntrepreneurshipEducation	Pearson Correlation	1	.388
	Sig. (2-tailed)		.212
	N	12	12
EntrepreneurialIntentions	Pearson Correlation	.388	1
	Sig. (2-tailed)	.212	
	N	12	12

Source: Field Data (2023)

There was no significant relationship between university entrepreneurship education and entrepreneurial intentions among second year target population of this study, r_{pb} (10)=.388, p=0.212Null hypothesis 2 was accepted because Point Biserial Correlation = .388, P value (0.212) is greater than Alpha value of the study (0.05) as illustrated in Table 2. The observed point Biserial correlation (0.388) is less than + or – 0.5760 and thus the correlation obtained in this study was not statistically significant at .05 level. This means that this observed correlation coefficient is not as a result of chance in a population where the true correlation in the population is zero. The findings are consistent with those of Ceresia (2018) which found out that entrepreneurship education does not influence entrepreneurial intentions among its recipients. Thus, we maintain that there is no significant relationship between entrepreneurship education and 2nd year students' intention to become entrepreneurs.

4.3 Year Three Results

The study intended to establish the correlation between entrepreneurship education and entrepreneurial intentions among 2nd year students as appears in Table 3. As the table shows, the p-value is greater than the critical value (0.05) and therefore the null hypothesis was rejected.

Table 3

Correlation between 3rd year students' entrepreneurship education and entrepreneurial intention

Correlations			
	University EntrepreneurshipEducation		trepreneurialIntentions
University Entrepreneurship Education	Pearson Correlation	1	-.084
	Sig. (2-tailed)		.796
	N	12	12
Entrepreneurial Intentions	Pearson Correlation	-.084	1
	Sig. (2-tailed)	.796	
	N	12	12

Source: Field Data (2023)

There was no significant relationship between university entrepreneurship education and entrepreneurial intentions among third year target population of this study, r_{pb} (10)= -.084, p=0.796. Null hypothesis 3 was accepted because Point Biserial Correlation = -0.084, P value (0.796) is greater than Alpha value of the study (0.05) as illustrated in Table 3. The observed point Biserial correlation (-0.084) is less than + or – 0.5760 and thus the correlation obtained in this study was not statistically significant at .05 level. This means that this observed correlation coefficient is not as a result of chance in a population where the true correlation in the population is zero. The findings disagree with those of Israr and Saleem (2018) which found out that entrepreneurial education has positive relationship with entrepreneurial intentions.

Thus, we maintain that there is no significant relationship between entrepreneurship education and 3rd year students' intention to become entrepreneurs.

4.4 Total Unit of Analysis Results

Table 4

Correlation between university entrepreneurship education and entrepreneurial intentions of student-teachers at University of Dar es salaam, Tanzania

Correlations

		University Entrepreneurship Education	Entrepreneurial Intentions
University Entrepreneurship Education	Pearson Correlation	1	.071
	Sig. (2-tailed)		.681
	N	36	36
Entrepreneurial Intentions	Pearson Correlation	.071	1
	Sig. (2-tailed)	.681	
	N	36	36

Source: Field Data (2023)

The observed point Biserial correlation (.071) is less than + or - .3494 and thus the correlation obtained in this study was not statistically significant at .05 level. Therefore, null hypothesis 4 was retained. The findings of the study are consistent with those of Nabi et al. (2018), who discovered that entrepreneurship education does not increase students' entrepreneurial intentions; rather, it informs them about entrepreneurship.

The study findings are differed with those of Bae et al. (2014), who discovered that entrepreneurship education has a statistically significant but small positive relationship with entrepreneurial intentions. The findings of the study are consistent with those of Nabi et al. (2018), who discovered that participants in university entrepreneurship education programs demonstrate greater entrepreneurial learning and inspiration than their non-EE counterparts. The average change in entrepreneurial intentions from the beginning to the end of the year, on the other hand, does not differ significantly between EE and non-EE participants.

Based on the findings in table 1 to table 4 above, there is no significant relationship between the education provided and the students' entrepreneurial intentions. was no correlation between studying university entrepreneurship educational having high entrepreneurial intentions among student-teachers at School of Education, University of Dar es Salaam Mwalimu Julius Nyerere

Mlimani campus. This was because r_{pb} (0.071) was not significantly different from zero at 34 degreesof freedom, 0.05 level of significance because it was below +.3494.

5.0 Conclusions and Recommendations

There was no statistically significant correlation between studying university entrepreneurship education and having entrepreneurial intentions amongst student-teachers at SOED in UDSM, both in year one, year two and year three as evidenced by this study, unless other studies that might be conducted at the same unit of analysis and the same foci prove otherwise. The implication of this study is that these findings justify further exploration of the foci of this study, so as to have a conclusive irrefutable position. It would seem appropriate to conduct further research: (i). Further studies should be conducted among student-teachers at SOED in UDSM to determine why there is statistically significant correlation between university entrepreneurship education and entrepreneurial intentions of student-teachers at SOED in UDSM. (ii). Further studies should be conducted among student-teachers at SOED in UDSM who receive university entrepreneurship education so as to determine why they are not highly enterprising. (iii). This study was conducted at undergraduate level at SOED. Further studies should be conducted at post graduate level at SOED.

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The Coming of Age of Open and Distance Learning in Higher Education in Kenya and its Potential Impact on Equity

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Abstract

One thing that was inherited from colonial education system is the place of equity in access to education opportunities at all levels and since independent the cure of this phenomenon has remained elusive. It is in this context that this paper focuses on the evolution, nature and promises of open and distance learning on promotion and enhancement of equity in higher education. In this scenario, I seek to address through critical analysis of relevant literature five things. First, I wish to give a conceptually brief but rich overview of distance learning and its encapsulation in education policy framework. Second, examine the impact and lessons from 22 years of existence of African Virtual University (AVU) in Kenya. Third, review the fundamental web of challenges and failures of adoption and adaption of open and distance learning in dual mode universities. Fourth, situate the development of open and distance learning institutions within the context of socio-political expediency. Finally, I wish to argue that our learning ecosystem has been embryologically nested in the evolution and nature of open and distance learning and that the recent initiative by the Government of Kenya to establish the Open University of Kenya is central in addressing and contributing to the recent call by UNESCO on "*reimagining our futures together*: *a new social contract for education*", and transforming educational ecosystem towards equity and inclusivity. The entire paper treats and discusses e-learning as a sub-set of distance learning.

Keywords: Access, Equity, Distance learning, Dual mode institutions, Learning ecosystem

Introduction

Though in the last fifty years, distance learning has globally gained popularity, its development, acceptability and visibility as the mode of learning vary from country to country. This popularity has arisen out of distance learning cost effectiveness, scalability of numbers, creation of learning opportunities to those who would not previously have considered this to be accessible or affordable route to higher education. In Kenya, distance learning can be seen from an evolutionary perspective. According to Ridley (2015), all institutions, practices, systems and services such as education and education technology, teaching and learning have all evolved overtime and the evolution process continues. In this perspective, distance learning needs to be seen in the context of general educational changes and learning ecosystem in the country. As a system of learning, distance learning is conceptually treated in this paper as a method of delivery of instructions and as a philosophy of learning. The evolution of formal education in Kenya can be seen from two perspectives, namely: the historical period and the sponsors' objectives. The question is: how was

education delivered prior to independence and after independent and when did the demand for distance learning emerge? Invariably, the development and support for open and distance learning is one way of scaffolding the recent UNESCO (2021) call for nations to situate their provision of education on three broad issues, namely: addressing historical injustice; current and future challenges.

Method

The information reviewed in this paper was gathered from various online and offline sources that included published journal articles in Google Scholar, books, government documents and reports, internet search for such key words as distance learning, education equity and inclusion, colonial education, micro-credentials.

Global Historical Perspective

Distance learning is a discipline that has developed over many centuries. It has emerged in the following forms and variants:

- Correspondence courses: - e.g., those conducted by Pitman for shorthand (Heydenrych & Prinsloo, 2010; UNESCO, 2000).
- Tuition for external examinations: -e.g., those offered by University of London and British Tutorial College (UNESCO, 2000).
- Off-campus, part-time or blended studies: -e.g., school-based, Executive MBA program offered by many local dual mode universities.
- 100% students off-campus: -e.g., Open University of United Kingdom; UNISA; Open University of Tanzania; Open University of Kenya.

In-Country Distance Learning Development Trends

Historically, the growth and the development of distance learning in Kenya is nested in several educational facets and variant sub-sets. Like an implanted embryo, it survived attempted abortions during its gestation period from colonial to post-colonial era. In this context, e-learning as a specialized delivery method is not a separate development from distance learning. Being a sub-set of distance learning, it is embedded in the development of distance learning. Introspectively, the genesis and the history of formal education in Kenya is short and the two broad periods in its growth and development are: colonial and post-colonial era.

Colonial Era

During the colonial period, the major sponsors of education were religious groups and the colonizer. The educational objectives of the two groups of sponsors were different though complementary. Up to the onset of the apex for struggle for freedom in early 1950s, the religious education was intended to support the colonizer to rule the colonized with ease and improve colonial economy. The colonial education on the other hand was limited to the development of functional literacy, manual and practical skills in carpentry, agriculture, masonry and other allied crafts and subordination. Requests for the establishment of higher education were severally rejected. The major beneficiaries of both religious and colonial supported education were males.

(Kithinji, 2023; Republic of Kenya, 2023; Mackatian, Imbovah, Imbova, & Gakungai, 2016; Mwiria, 1991). During the entire colonial era the demand for distance learning was limited.

Post-Colonial Era

Specific developmental catalysts and milestones that contributed to the maturity and the coming of age of distance learning include: cross-border education; flexible entry, exit and re-entry system; early use of radio; adult and continuing education concept; print-based; education reform commissions and policy position; CCTV concept of 1990s; emergenceof e-learning: the case of African Virtual University; dual mode development; enabling legal framework: Universities Act of 2012; and COVID 19 pandemic contribution.

Cross-Border Education

During colonial era, few Kenyans studied for secondary and university qualifications through correspondence offered by such institutions as Rapid Results College; Wolsey Hall Oxford; University College London; University of South Africa; University of Fort Hare. In post-colonial era Rapid Results College; University of South Africa; University College London; and British Tutorial College continued to offer cross border education.

Flexible Entry, Exit and Re-entry

The earlier system of education had in-built flexibility. At the high school level, the education system opened windows of opportunity and progression:

- KJSE: Provided teachers with the opportunity to accumulate passes for promotion from P3 to P2.
- KCE: Standard eight graduates, P3 and P2 teachers continued to study privately or through correspondence institutions for KCE qualifications and promotion to P1 teaching grade.
- KACE: KCE graduates and P1 teachers continued to study privately or through correspondence institutions for KACE qualifications for entry to university or promotion for those who were teachers to S1 or SA teaching grade or approved graduate grade.

The flexibility that was inbuilt in the education system underlined the concept of ‘openness’. However, following subsequent reforms in education these windows of opportunity for accessing education through distance learning at the secondary level have been gradually closing down. The 8-4-4 narrowed progression through off school avenues. In view of its formative assessment approach, CBC has completely sealed off school progression ladder outside school context. The question now is: how will those who fail to continue at different stages of basic education continue?

Early Use of Radio

The earliest educational technology to be used in Kenya to deliver instructions is the radio. In late 1960s and early 1970s the Ministry of Education through the former Kenya Institute of Education delivered primary and junior secondary school lessons through radio. In 1980s, Ministry of Education and the Ministry of Health carried out in-service teacher training and in-service training

of health workers through the use of radio (Jenkins, 1990a, 1990b; Hawkridge, Kinyanjui, Nkinyangi, & Orivel, 1982).

Adult and Continuing Education concept

In many instances the evolution of adult and continuing education (ACE) in this country has not been seen as part of the evolution of distance learning. ACE is indeed a variant of the current understanding of distance education. The idea of ACE emerged from the fact that at independence there was a large proportion of citizens who were either denied education or restricted in progressing to the next level by the colonial regime. In addition, one of the agenda of the uhuru government was the elimination of ignorance and hence one vehicle for doing this was through ACE (Republic of Kenya, 1964).

The nexus between ACE and distance education is the philosophy that underpins both, namely: provision of education at a convenient time or in a flexible mode to persons who have other national, cultural, or family responsibilities to attend to; giving those interested a second chance to actualize their educational dreams; and using different teaching and learning methodologies from those of younger learners. It is in this context that ACE has been discussed by all education reform commissions, committees, and taskforces.

Print-Based

In 1962, the Institute of Adult Studies based then at Kikuyu was established to be in charge of distance education. Before introduction of e-learning, the unit, renamed ODeL Campus in 2016, utilized print-based materials developed through the support of UNESCO. In 1990s, the print study materials for B.Ed. program were loaned to the Open University of Tanzania to start off its B. Ed. program. Similarly, between 1997 and 2004, Egerton University utilized print study materials for its Military Science Certificate and Diploma program. To this day, Egerton University continues to use print materials to deliver its Master's degree program in South Sudan.

Education Reform Commissions and Policy Position

The various education reforms commissions and committees that have been set up by the government made recommendations touching on the support for distance learning or the elements of distance learning as follows:

- *Kenya Education Commission (1964):* Recommended strengthening adult and continuing education and inclusion of prior learning in admission to engineering program at the University of Nairobi (p.96)
- *Report of the Presidential Working Party: Second University in Kenya (1981):* Recommended that a College of Continuing Education be established as part of the university educational system. The College should be attached to the Second University so as to provide university education to those who otherwise might not have had such an opportunity (p. 54-55).

- *Sessional Paper No. 6 of 1988 On Education and Manpower Training for the Next Decade and Beyond.* Noted that the government accepts the recommendation of the Working Party that distance education be expanded and increasingly adopted as a more cost-effective method of offering education (p.35).
- *Sessional Paper No.1 of 2005 on A Policy Framework for Education, Training and Research:* Noted the need for the promotion of open universities, and distance education to increase learning opportunities (p. 56). One of the objectives of the MoE stated in the Paper is "to promote and popularise open and distance education at all levels of education and training by 2010". It identified open and distance learning as an option in "expanding access to basic and subsequently, higher education".
- *Transformation of Higher Education and Training in Kenya to Secure Kenya's Development in the knowledge economy: Report of the Public Universities Inspection Board (2006).* Observed and recommended:
    a) Distance education programmes in higher education are generally disjointed and run on *ad hoc basis*.
    b) The government should…establish Open University of Kenya by 2008 drawing on the experiences and expertise available in the local universities, the Africa Virtual University, African countries and the Commonwealth of Learning (p.47).
    c) Access to tertiary institutions should be opened to those who have acquired knowledge, skills and competencies in non-formal settings in addition to the current practices of admitting students who have gone through the formal school system and attained the required academic admission criteria (p.38).
- Rumble (2008*). Establishing a distance-teaching national university in Kenya. Report to the Permanent Secretary, Ministry of Higher Education, Science and Technology.* The report advised the Ministry on how to design and plan for the establishment of the Open University of Kenya.
- *Reforming Education and Training Sectors in Kenya: Sessional Paper No. 14 of 2012*
    a) Expansion of open and distance education in existing universities.
    b) Establishing the Open University of Kenya by 2014.
- *National Education Sector Strategic Plan 2018-2022*: Notes that the objective of the Ministry of Education on access to university education: "is to strengthen and expand e-learning programmes in all universities. --- with a target of having 30% of the degree programmes available on e-learning mode" by the end of the planned period (p. 69).
- *Presidential Working Party on Education Reform (2023).* Recommended:
    a) MoE to operationalize the Open University in Kenya by 2023/2024 financial year.
    b) CUE to review the University's Standards and Guidelines, 2014, to provide criteria on minimum admission qualifications for OUK.
    c) MoE to develop a National Policy Framework on open distance and e-learning.

CCTV Concept of 1990s

In view of the challenges of teaching large classes in 1990s, universities held a conference with UNESCO on the option of using closed circuit television (CCTV) technology in 1996 (UNESCO, 2000). This technology was to permit a simultaneous presentation of a subject/lecture to a large number of students or students spread in different lecture halls. Due to infrastructural logistics and cost this approach never took off.

Emergent of E-Learning: The Case of African Virtual University

The institutionalization of online learning in Kenya emerged in late1990s when the World Bank financed the establishment AVU as an ICT driven institution with Kenyatta University and Egerton University being the founding partners. The whole idea behind AVU establishment was increasing access to higher education. As a project, the WB supported its operations including the delivery of short-term courses through both synchronous and asynchronous communication across all partner institutions in Africa from universities in USA, Scotland and Australia.

Like many donor projects, AVU collapsed in 2021. The peripheral impact of AVU to local partner institutions included: the establishment of Open Distance e-Learning (ODeL) centres, acquisition of computers and VSATs, support for the development of programs such as Applied Computer Science, creating consortium of academic staff to jointly develop modules, and catalyzing initiation of online learning programs. The greatest impact of AVU in higher education in the African continent include the development of over 1300 OERs that are available for use by all institutions across territorial boundaries. With this peripheral impact, the big question is: did we accommodate and assimilate the philosophy that underpinned the establishment of AVU? If so, why did COVID 19 pandemic find us unprepared or found our e-learning in fragile state and yet AVU had been in existence in Kenya for 20 years by then?

Dual Mode Development

As part of revenue generation, public universities started tuition paying streams in late 1990s. This led to the establishment of satellite campuses, evening and weekend classes. This came at the time the government had conceded to the World Bank pressure on university reforms and cost sharing. By 2000, all public universities had adopted the creation of self-sponsored streams including school-based and in some universities this stream raised up to 60% of the total revenue. However, this dual and semi-distance mode had serious flaws including:

- *Limited cross-border application.* The distance learning courses are largely restricted to the domestic economy and hence are available only those within the territory of Kenya.
- *Duality of assignments.* Lecturers who are assigned to facilitate those who study under distance learning stream are also assigned to teach on-campus students. They treat distance learning facilitation as a part-time assignment and give more attention to traditional students.
- *Low interactive delivery.* Course materials are not digitized and are made available to students in PDF, compendium, and lecture notes posted online.

- *Traditional management practices.* The practices being applied are conventional such as deferment, scheduled examinations, failure to physically attend 80% of class hours and hence not in compliant with ODL best practices.
- *Unsustainable venture:* The campuses that were established to cater for Module 11 stream of learners proved unsustainable.
- *'Open Learning'.* Using 'open learning' for marketing purposes only otherwise no traces of openness in institutional practices.
- *Peripheral presence.* ODL unit is treated and offered as peripheral unit within the university structure.
- *Limited resources.* ODL unit suffers from poor funding and staffing.
- *Low learner support services.* Lecturers treat their participation in teaching distance learners as a part-time assignment; learners have challenges accessing their course facilitators or getting prompt response; and due to delays in processing their assignments and examinations distance learners take longer time to graduate.
- *Low institutional championship.* The unit often the first target on downsizing and restructuring of the university.
- *'Cash cows' status of learners*. Use of distance learners as 'cash cows' of the institution. The resources received from distance learners are utilized by the institutions to develop facilities for the benefit of conventional students such as building additional classrooms and office blocks; and purchase of buses.

Enabling Legal Framework: Universities Act 2012

Equitable access to education at various levels are documented in various policy documents and statutes. At the university level, Universities Act of 2012 provides two distinctive elements of distance learning, namely: recognition that it is a specialized discipline that needs to stand alone in an education discourse; and promises under section 3 (2) (b) and (c) that in discharging its function a university shall enhance equity and accessibility to its services. The previous Universities Act of 1985 had no provision on distance learning. Distance learning reached its apex in this country when OUK was finally established in 2023 under this Act as a specialized University.

Covid 19 Pandemic Contribution

Though COVID 19 pandemic posed unprecedented challenges and negative impact on the delivery of social services including education, it raised conversations on the alternative ways of teaching and learning. When traditional system of education delivery that has been in place for centuries collapsed, institutions resorted to remote learning. Consequently, disparities in equitable access to learning resources were widened. A Communique[1] of the African Union STC-EST 3 noted on

[1] STC-EST3 Bureau of the Specialized Technical Committee on Education Science and Technology of the African Union

April 9th 2020 that the effects of COVID-19 were "worsening existing weaknesses in Africa's Education systems". The Communique further acknowledged "that unless we collectively act now to protect Education systems by providing alternative learning platforms and complementary programs, societies and economies will feel the burden long after COVID-19". In Kenya, the Ministry of Education and the universities resorted to the use of various edtech to keep teaching and learning going. The long-lasting impact of COVID 19 on higher education has been enhancing and entrenching the acceptance and visibility of e-learning as a mode of learning.

What are Our Equity Barriers?

One misconception of equity is using high enrollment in university as a measure. Increase in students' enrollment in university as a result of increased number of universities does not translate to equity. The overall enrolment among girls in university and in STEM programs is still lower than that of boys; those from remote locations are still excluded; and those with accumulated work experience are also excluded. Additionally, access barriers that have been identified include: cultural, socioeconomic, mode of study, policy induced and imposed, transhumance lifestyle, and technological. Open and distance learning has potential of addressing historical injustices that have inhibited access to education and thus promising a prosperous future that is equitable.

Cultural Barriers

Culture plays a role of either being a facilitator or an inhibitor of one's success and participation in productive activities. In his book *The Achieving Society,* McClelland (1961) demonstrated that the disparities in economic development across societies of the world is rooted in culture. In his cross-cultural analysis of over 100 cultures that included the Chagga of Tanzania and the Kikuyu of Kenya, McClelland found that cultures that were economically better off had people with high need for achievement. In addition to believing in protestant ethics, he attributed the causes of the need to achieve to child-rearing practices that give children more independence and mastery in childhood and encourage taking calculated risks. This is a positive role of culture. However, in a multicultural society like Kenya, there are also prevalent negative aspects of culture that curtail individual's socioeconomic development and educational achievement. There are still pockets of communities that do not value the education of girls. Their investment in girls' education with respect to giving them opportunities to progress in education to higher levels is low (Mwakio, 2017).

Socioeconomic Barriers

In 2023, 16.1% of Kenyans live below international poverty line (World Bank, 2023). One of the factors that affect the standard of living and the ability of a family to provide services such as education is poverty. In educational context, poverty has significant impact on children's access to equality education. The majority of those who meet the conventional university's minimum entry requirement come from national and private high schools. These happen to be high-cost schools. From this perspective, socioeconomic status has already pre-selected potential university qualifiers.

Mode of Study Barriers

Traditional mode of study is a barrier to those who have other responsibilities or physical limitations. This mode assumes that all learners are either young or have no other responsibilities other than to study. There are other potential learners who are in confined situations or restricted by exigencies of duty or religious practices or distance or natural barriers.

Policy Induced Barriers

Policies that have been put in place have been intended to address challenges of equitable access to education at various levels arising out of an array of factors. However, these policies have led to the construction of exclusion in higher education. The greatest policy induced barriers have been:

- *The cut-off points for admission*: Universities peg their admission level on the basis of two things: operational cost, and the capacity of teaching and learning facilities. In view of relatively low fees charged by public universities because of government subsidy and their worldwide recognition and reputation, most qualified candidates prefer to enroll in public universities. In view of low absorption capacity of these universities particularly in 1990s and early 2000, they kept raising their cut-off points for admission. This policy lowered the chances of children who attended less endowed and resource constrained high schools from accessing programs of their choices at the university and hence perpetuated exclusion.
- *Financial support:* The financial support that has been intended to facilitate the less fortunate learners such as bursaries and loans have inbuilt challenges of identification, political patronage, and need assessment. There are reports that students report to university and then defer studies for failure to secure adequate financial support.
- *Scholarship:* This support is only for the best performers irrespective of socioeconomic status and hence average performers from poor backgrounds are outside this bracket.
- *Dual mode practice for online learners:* This framework has failed to provide equitable access and support services that enhance learning in two ways: first, access to this mode and stream of learning is based on ability to pay and second, low learner support services, a resource that is critical for the success of distance learners.
- *Denial of access to higher education on age grounds:* Government denial of financial support such as bursaries to learners who are over 25 years old.

Imposed Barriers: Free Trade Concept

The imposed barrier came in the form of imposition of free trade concept in education sector in developing nations by Bretton Woods Institutions. Contrast to the treatment and conception of education as public venture and a common good and hence a vehicle for promoting equity and inclusion, the conversion of universities in 1990s into free-markets for the sale of education under the World Trade Organization (WTO) banner of "trade in education services" was a blow to equity and inclusion in higher education. The World Bank enforced this free-market concept through loan lending practices and conditionalities.

Through the World Bank financed Universities Investment Project extended to the Kenya government in 1991, two things entered public universities' scene. One was the start of students

paying tuition, meals and accommodation through loans and second, universities were expected to raise extra revenues. It is this concept of extra revenue generation and the high demand that forced universities to start Module II. By 2005, 85% of the candidates who achieved university eligibility grade of C+ and above at KCSE could not be admitted by public universities (Republic of Kenya, 2006). While the Module II stream increased access to university, it failed to enhance equity. Only those who were financially endowed accessed the university education (Wainaina, 2011; Republic of Kenya, 2006).

Transhumance Lifestyle Barriers

There are still pockets of people whose subsistence economy and livelihood involve constant movement from place to place. Access to education for such communities requires non-physical and flexible mode of delivery.

Technological Barriers

Learners with disabilities particularly the visually impaired learners have faced challenged when they are admitted to conventional universities without assistive technologies (Republic of Kenya, NESSP, 2018-2022).

The New Horizons of Distance Learning

Political Expediency and Landscape

Globally, education development and reforms are politically driven. Invariably, the establishment of public open universities including the Open University of United Kingdom, the Open University of Tanzania, and Zimbabwe Open University were anchored on and driven by the political agenda and leadership of political party in power. In Kenya, the mainstreaming of distance education and the establishment of the Open University remained dormant for decades despite the recommendations of various education commissions. It is the championship and the political goodwill of the current government that the Open University of Kenya was finally established in 2023.

Investing in Distance Learning

One of the World Bank's (2000) prescription for Africa's development in the 21st century is investing in the social sector. The establishment of OUK to move ODL from the periphery in the chain of education supply to the centre calls for new investment. Prosperous future that is equitable demands that a country invests in education provision that the lower income population can afford, the number that Collier (2008) referred to as "the bottom billion" and are locally called "the hustlers".

Reframing internalization concept

For a long time, we have looked at the concept of internalization of our universities in the form of attracting foreign students to our local institution (Republic of Kenya, 1981; Republic of Kenya, 2006; Republic of Kenya, 2023). What about exporting our programs?

The history of education shows that Kenya has been primarily an importer of higher education for a very long time. This importation is defined by WTO "mode of supply" summarized by Knight (2004, p. 9) as cross border supply, consumption abroad, commercial presence, and presence of natural persons. Though Kenya has remained primarily an importer based on the four WTO modes

of supply of education services, Kenyan universities have made attempts though insignificant to export education as follows:

- Egerton University: Twinning partnership with Western Michigan State University in early 2000 and offering of a military science program in South Sudan.
- Kenyatta University: Setting up a campus in Tanzania.
- Jomo Kenyatta University of Agriculture and Technology: Setting up a campus in Rwanda.
- Mount Kenya University: Campus now present in Rwanda.

The question is: is Kenya now ready to supply or export cross-border higher education? The answer is in affirmative. Advances in learning technologies have changed WTO supply mode 3 (commercial presence) and 4 (presence of natural persons). Taking advantages of these technological advances make supply mode 1 (cross border supply) viable mode for OUK's exportation of higher education from Kenya.

Depreciating Exclusion

Disparities in equitable access to educational opportunities arising out of inhibitions imposed by culture, socioeconomic status, induced policies, study mode and free trade concept that commercialized education need to be repaired. These practices have established exclusion as a norm. The question now is: how do all Kenyans share the prosperity envisaged in Kenya Vision 2030 if exclusion is not depreciated? UNESCO's (2021) states that "if education is to help transform the future, it must first become more inclusive by addressing past injustice" (p.23). OUK vision "innovative university for inclusive prosperity" intends to transform the learning ecosystem towards greater equity through:

- Openness

Why can a 66-years old applicant who has retired from active service and who got Division 4 in KCE or grade D in KCSE at the age of 18 not join a conventional university to purse a degree of her/his choice? In adherence to its vision of inclusivity, OUK practices true meaning of openness with respect to: application of regular admission criteria; and admission through recognition of prior learning. Under these conditions, the above 66-years old applicant can be admitted to OUK provided he/she proves that she/he can succeed in a university program. Ability to succeed assessment is to safeguard the applicant's value for money.

- Flexibility

Flexibility with respect to OUK includes the following facets: asynchronous communication mode; choice of course load; introduction of micro credentials; provision of "a" learning-anytime, anyplace, and anywhere learning; examination on demand upon completion of a course on next offered examination time basis; and stepping out and stepping in depending on learner's exigencies of other responsibilities.

- Affordability

Affordability does not necessarily mean cheap. It is anchored on: fees paid on the basis of the number of courses taken; potential fees decline in the long run on the basis of economies of scale; technology choice; and elimination of accommodation fees.

- Equity Enhancing Technology

Disparities in learners' access to study materials can be attributed to many factors including devices and network at learner's disposal, some of which are beyond the control of the education provider, the Open University of Kenya. In this context, OUK is in control of technological soundness of the delivery mechanisms. The equity issue is: can the materials be delivered in forms that the learners can access? Online technologies that have been put in place that every learner can access and learn from them include: Google Drive for documents and presentation slides; and the Learning Management System (LMS) for group chats and discussion forum.

Further areas of Conversation and Contestation

Access gap still exists

While OUK is currently structured to handle access to higher education, what about those who for one reason or another cannot complete either primary or secondary education? In view of individual's constitutional rights with respect to access to education and SDG4 in respect to leaving nobody behind, the country needs a conversation on the extension of open and distance learning to primary and secondary sectors as promised by the Sessional Paper No 1 of 2005. Even with 100% transition policy of 2020, 16% drop out at end of four-year period.

Regulatory framework

OUK presents a new learning ecosystem. With the emergent of OUK, the regulations that govern the entire higher education ecosystem need a review including but not limited to:

- Collaboration

We need to look at institutional collaborations as guided by CUE in local and global context and ask ourselves: what are our regulations guarding against? What about process of customization of programs from other accredited universities? Are our regulations accommodating cross-breeding of programs for cross border consumption? What about emerging developments such as OERs and MOOCs?

- Assessment

The Outcomes Based Education (OBE), known in Kenya as CBC that is being implemented puts heavy weight on formative assessment or assessment for learning. It sounds good at the primary level. At the university level we ask ourselves: how do we do this without compromising quality and international acceptability of our grading? In this new learning ecosystem, we need a conversation on the new approach to assessment.

- Micro-credentialization of learning

This is an emerging development in Europe Union, Southeast Asia and Hong Kong. According to European Commission, European citizens will be able through micro credentials to start their

learning pathways into and through higher education at any stage in their life time by 2030. It is been seen as one way of creating flexibility in higher education and enhancing employability.

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Perceived Impact of Entreprenuership Education as a Tool for Job Creation, Poverty Reduction and National Development in Katsina State Nigeria

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Abstract

This paper examines the perceived impact of entrepreneurship education as a tool for job creation, poverty reduction, and national development in Nigeria. The study adopted a descriptive survey design. The population of the study consisted of 420 entrepreneurs who graduated from six business apprenticeship training centers (BATCs) in Katsina state and graduated students of the Business Education Department, Federal College of Education, Katsina 2021/2022 session. A stratified sampling technique was used in the selection of the sample. The sample size of 201 graduates was used, determined by Krejcie and Morgan (1970). The research instrument was a structured questionnaire developed for the study. The instrument was validated by experts and its reliability was determined using Cronbach alpha Reliability Coefficient (α = 0.79). Two hypotheses guided this study. Data gathered from the questionnaire were analyzed using regression analysis. The results of the study revealed that entrepreneurship education had a significant impact; In particular H_1 and H_2 is Strong with regression weight 0.739[$p<0.001$] and 0.730 [$p<0.001$] respectively on job creation, poverty reduction, and national development in Nigeria and graduates from BATCs acquired more entrepreneurial skills than graduates of Federal College of Education, Katsina due to more engagement in practical training. The study thus concluded that entrepreneurship education plays a crucial role in job creation, poverty reduction, and national development. The study recommends that the government should introduce entrepreneurship training centers in the Colleges of Education in Nigeria for practical skill acquisition among the students, provide adequate funds and equipment for the operation of the training centers, and ensure that both students of BATCs and Colleges of Education has access to loans, financial assistance or equipment for enterprises development after graduating.

Keywords: Entrepreneurship Education, Job creation, National Development, Poverty reduction

Introduction

Education has been identified as the engine of national development. It plays a crucial role in social well-being, job creation, poverty reduction, and the improvement of people's living standards. Efe (2014) posited that education is a vital tool in the training and development of human resources in any country by imparting essential skills, capacities, values, knowledge, and attitudes that can be

utilized in the transformation of individuals, communities, nations, and the world at large. According to Maina's (2013) assertion, education serves as the crucial instrument for national development. By unlocking the economic capabilities of individuals, it empowers and equips them to actively participate in and derive benefits from their nation's economy. Additionally, education facilitates economic growth and fosters transformation by providing the foundation for it.

In contrast, entrepreneurship education focuses on equipping young individuals with the necessary skills, competencies, knowledge, and traits to become innovative and to establish and manage their own businesses. This form of education not only promotes job creation, poverty alleviation, and national development, but also contributes to economic growth. The primary objective of entrepreneurship education is to enhance entrepreneurial self-efficacy, self-employment, and risk-taking behavior among potential entrepreneurs. Entrepreneurship education creates enormous business opportunities and trains people with innovative enterprise skills to grasp the opportunities for starting new entrepreneurial activities (Cheng and Chan, 2009). In addition, Entrepreneurship education has various benefits to individuals and the nation. It will provide the young graduates with adequate training that will enable them to be creative and innovative in identifying great business opportunities. It will also offer functional education to the youths to enable them to be well-empowered and self-reliant people in their own right and serve as catalysts for economic growth and development. In addition, it offers tertiary institution graduates adequate training in risk management to make learning outcomes feasible and reduce the high rate of poverty and insecurity as well as violence.

Entrepreneurship education will not only foster economic growth, but it will also create employment opportunities for the citizens and reduce the migration from rural areas to urban centers. This will lead to sustainable development and provide young graduates with the necessary skills and support to establish successful small and medium-sized businesses. By incubating a spirit of perseverance in both youth and adults, entrepreneurship education will enable individuals to persist in their business ventures and facilitate a smooth transition from traditional to modern industrial economies. Additionally, entrepreneurship education has been shown to be an effective means of poverty reduction, as economic growth over time is crucial for reducing poverty levels. Entrepreneurship boosts economic growth, enhances educational attainment, and increases the rate of economic growth (Mitra and Abubakar, 2011). Entrepreneurship education plays a significant role in changing students' views towards becoming self-employed. This is because entrepreneurship education is meant to train students upon graduation to become self-reliant and employers of labor through creative and innovative thinking in identifying new business opportunities Kamar et al, (2021).

Entrepreneurship education has numerous advantages for both individuals and the nation. It equips young graduates with the necessary skills to identify and seize business opportunities, while also providing functional education to empower and make youths self-reliant, serving as catalysts for economic growth and development. Moreover, it offers tertiary institution graduates risk management training to make learning outcomes feasible and reduce poverty, insecurity, and violence. The purpose of this study is to explore the perceived impact of entrepreneurship education as a tool for job creation, poverty reduction, and national development in Nigeria.

Statement of the Problem

The objectives and goals of entrepreneurship education seem not to be realized in that youths/graduates finish their education and are unable to engage themselves as self-employed persons based on their career choice and on skills acquired while studying entrepreneurship education. Akpochafo & Alika (2018). The problem of entrepreneurship education is not about curriculum or investment in education nor is it non-availability of manpower for the sector, but that many have tended to look in the direction of management of education which includes lack of policy analysis to make students fit into society, yet not relying on the government of the day but the managerial ingenuity of educational managers and administrators to make education a building block of employment creation, self-reliance, crime reduction, socio-economic empowerment, prosperity, national security, as a means for achieving sustainable national development through improved access to quality, functional entrepreneurship education at all levels. Adedayo et al, (2023 P.3). It was also opined that Students graduate from the Universities and Colleges of Education including Technical schools, only to add to the teeming number of unemployed persons despite the entrepreneurship education enshrined in the curriculum for Universities and Colleges to encourage self-reliance Mohammed at el, (2014 P.1). Such entrepreneurship courses were ideally introduced to enhance self-reliance among the graduates. This has not yet been achieved, hence the need to study the impact of entrepreneurship education as a tool for job creation, poverty reduction, and national development in Nigeria.

Objective of the study

The general objective of this study is to examine the perceived impact of Entrepreneurship Education as a tool for job creation, poverty reduction, and National Development in Nigeria. Specifically, the study aimed at the following:

1. To investigate whether entrepreneurship education has effect on job creation for National Development in Nigeria
2. To determine the impact of entrepreneurship education on poverty reduction for National Development in Nigeria
3. To examine the strategies for enhancing Entrepreneurship Education toward National Development in Nigeria

Research Question

1. What are the strategies for enhancing Entrepreneurship Education toward National Development?

Research Hypotheses

H_{01}: Entrepreneurship Education not effected Job creation for national development in Nigeria.
H_{02}: Entrepreneurship Education not impacted poverty reduction for national development in Nigeria.

Conceptual Review

Entrepreneurship Education

Entrepreneurship education focuses on developing attitudes, behaviors, and capacities at the individual level. It also encompasses the application of these skills and attitudes, which can

manifest in various forms throughout an individual's career, generating a range of long-term benefits to society and the economy Efe (2014). Aliu (2014) posits that Entrepreneurship Education is learning directed towards developing in young people those skills, competencies, understandings, and attributes that equip them to be innovative and prepare them to identify, create, initiate, and successfully manage personal and/or community business, and work opportunities, including self-employment. Akudolu (2010) asserts that the primary objective of entrepreneurship education is to promote creativity, innovation, and self-employment among citizens through the inculcation of entrepreneurial knowledge, competencies, and attitudes in the learner.

Job Creation

Ayorinde et al (2017) posited that "Job Creation" refers to the concept of employment opportunities being generated in response to specific events or circumstances. This phenomenon can be observed when individuals engage in meaningful activities that enable them to support themselves and their immediate families, contributing to the physical and economic development of a nation.

Poverty Reduction

Poverty encompasses the lack of income or shortage of assets, the absence of competence and confidence, disempowerment, and the deprivation of national currency. Additionally, it is common to refer to a poor understanding, culture, or spirit (Singer, 2006). Poverty may arise from the low productivity of households, which face financial constraints and a lack of other incentives for entrepreneurship (Adenutsi, 2009). The World Bank also posits that political instability, inadequate infrastructure improvement, insufficiency of national policy and structural adjustment, and lack of investment are among the primary causes of poverty (Misango and Ongiti, 2013). Poverty is widely conceptualized as a condition of living on income below a certain minimum threshold. The World Bank defines those living under US$2 a day as living in poverty, and those living under US$1.25 as living in extreme poverty internationally (Chen and Ravallion, 2008).

National Development

According to UNESCO (2000), the capacity of a nation to enhance the social welfare of its populace, for instance, by providing social amenities such as quality education, potable water, transportation infrastructure, and medical care, extends beyond the mere provision of these amenities. This observation underscores our contention that this definition is insufficient in capturing the complete picture, as it tends to overlook the economic component of the developmental process. National development encompasses the improvement of all spheres of human endeavor that ultimately ensures sustained welfare for citizens of any society (Eferakeya and Ifurueze, 2016). This implies that to achieve national development, there should be availability of employment opportunities and a reduction in poverty within the community. Umoren et al (2018) posited that national development is a function of the development of individuals and corporate entities within the country. National Development, in a broad sense, encompasses general development in communities, towns, cities, states, and nations as a whole in the best interest of its people. A country can enhance its human capital, economy, social welfare, democracy, infrastructure, national defenses, and other key sectors of national life. National Development refers to the ability of a country to improve the socioeconomic welfare of its people

by providing social amenities such as quality education, clean pipe-borne water, adequate roads, electricity, transport, and communication (Uchenna and Uju, 2020).

Literature Review

Entrepreneurship education has gained significant attention in recent years as a potential tool for job creation, poverty reduction, and national development. It has been widely recognized that entrepreneurship plays a vital role in driving economic growth and creating employment opportunities (Radebe, 2019). The impact of entrepreneurship education on poverty alleviation in Nigeria is highlighted as significant, contributing to economic growth, job creation, and the development of entrepreneurial skills Drenket and Gotip, (2018). According to Efe, (2014), Entrepreneurship education is a solution to unemployment, poverty, and national insecurity by equipping individuals with the skills and knowledge to create their opportunities. Maina, (2013) asserts that entrepreneurship education in Nigeria; has the potential to achieve national development goals, reduce unemployment, and alleviate poverty. Ifeoma et al, (2018) claimed that Entrepreneurship development is a key tool for poverty reduction; stimulating employment and economic growth in developing countries. Kamar et al, (2021) opined that entrepreneurship education plays a significant role in changing students' view towards becoming self-employed. Hussain and Bhuiyan (2014) posit that entrepreneurship development is a key tool for stimulating employment and reducing poverty. Mani, (2017) argues that changes are needed in the learning process to promote entrepreneurship and that entrepreneurship should be associated with creativity and change. Lack of experience and funding were identified as major deterrents for starting a business immediately after college. In line with these more practical skills are recommended. Uchenna and Uju, (2020) affirm that entrepreneurship education is a veritable and practical option to remedy the consequences of the global economic implosions and put the nation on the path of national development. Eferakeya and Ifurueze, (2016) opine that the entrepreneurship education curriculum is inadequate, lecturers teaching entrepreneurship education are not adequate in number and competent enough and it is not well funded.

Theoretical Review

The Need for Achievement Theory (NAT)

The theory shows the functional relationship between the need for achievement, economic development, and entrepreneurial activities. According to McClelland (1956), entrepreneurial activity is the potent process by which the need for achievement leads to economic growth. He opines further that one would expect a relatively greater amount of entrepreneurial activities in a society if the average level of need achievement is relatively high among the people (Eferakeya and Ifurueze, 2016).

Risk Taking Theory

According to Alam and Hossan (2003), this theory sees entrepreneurship as a mental education that stimulates individuals to take moderate or calculated risks for which they stand to enjoy streams of benefits. It makes people take bigger risks to contend with great responsibilities. The theory underscores that entrepreneurship education improves the ability, capability, and potential of the human capital of a nation to undertake risks for which all stand to benefit immensely (Sofoluwe et al, 2013).

Methodology

A descriptive survey research design was adopted for this study. The population of the study consisted of 300 youth who graduated from six Business apprenticeships Training Centres (BATC) in Katsina state and 120 students graduated from department of Business Education, Federal College of Education, Katsina 2021/2022 session. This made up the total population of 420 graduates. The sample of the study was 201 determined by Krejcie and Morgan (1970). The graduates were selected using a stratified sampling technique. The research instrument was a structured questionnaire developed for the study; Four-point rating scale structured questionnaire was used to collect data from the respondents. The instrument was validated by experts. The instrument was pilot-tested using 30 respondents. Data collected from the pilot study were subjected to statistical analysis using test-retest, and its reliability was determined using Cronbach alpha Reliability Coefficient ($\alpha = 0.79$) which showed that the instrument was reliable for the study. Data gathered from the questionnaire were analyzed using regression analysis.

The questionnaires were distributed to the target respondents and one hundred and ninety two (192) copies of the questionnaire were retrieved and subjected to statistical analysis, where the mean score of 2.5 and above was considered as an index for acceptance while regression analysis was used to test the two (2) research hypotheses. All the null hypotheses were tested and rejected at a $p<0.05$ level of significance.

Results

The followings are the results of the findings and interpretations of this study.

Objective one: To what extent does Entrepreneurship Education has effect on job creation for National Development in Nigeria?

Table 1

The extent to which Entrepreneurship Education has effect on job creation

Opinion	N	Total score	Mean	Std. Dev.	Decision rule	Decision
Agree	132	428	2.8	1.3	2.8 > 2.5	Agreed
Disagree	60	108				
Total	192	536				

Source: Field Survey, 2023

Table 1 answered research question one. The table showed that, 132 respondents with a total score of 428 had the opinion that, Entrepreneurship Education has significant effect on job creation for national development. While 60 respondents having a total score of 108 were of the view that, Entrepreneurship Education has no significant effect on job creation for national development. Therefore, result shown that, Entrepreneurship Education has significant effect on job creation for national development, because the mean score (2.8) is greater than the 2.5 bench mark for agreement.

Null hypothesis one: There is no significant effect between Entrepreneurship Education and Job creation for national development in Nigeria.

Table 2

Effect of Entrepreneurship Education on job creation for national development

Model	B	Std.Err	t.	R-crit	R-cal	R^2	adjustedR^2	Sig
Est. center for Entr.	**17.724**	**.434**	**5.272**	**.088**	**.739**	**.058**	**.057**	**.000**
Job creation	**.236**	**.232**	**1.437**					

Source: field Survey, 2023

Table 2 presents regression analysis of the effect of Entrepreneurship Education on job creation for national development. From the table, the computation indicated a calculated r value of 0.739 greater than the critical r value of 0.088 at 0.05 level of significance ($p<0.001$). The result indicated that, Entrepreneurship Education has significant effect on job creation. Therefore, the null hypothesis which states that, there is no significant effect between Entrepreneurship Education and Job creation for national development in Nigeria was rejected.

Objective 2 two: How does entrepreneurship education impact on poverty reduction for National Development in Nigeria?

Table 3

The Extent to which Entrepreneurship Education has Impact on Poverty Reduction

Opinion	N	Total score	Mean	Std. Dev.	Decision rule	Decision
Agree	129	418	2.7	1.3	2.7 > 2.5	Agreed
Disagree	63	107				
Total	192	525				

Source: Field Survey, 2023

Table 3 answered research question two on how does entrepreneurship education impact on poverty reduction for National Development. The table revealed that, Entrepreneurship Education has significant impact on poverty reduction for national development. This is because the mean score (2.7) is greater than the 2.5 bench mark for agreement.

Null hypothesis two: There is no significant impact between Entrepreneurship Education and poverty reduction for national development in Nigeria.

Table 4
Impact of Entrepreneurship Education on Poverty Reduction for National Development

Model	B	Std.Err	t.	R-crit	R-cal	R^2	adjustedR^2	Sig
Prov. of free Interest loan	19.624	.454	5.973	.088	.730	.052	.049	.000
Poverty Reduction	.421	.232	1.657					

Source: field Survey, 2023

Table 4 presents regression analysis of the impact of Entrepreneurship Education on poverty reduction for national development. From the table, the computation indicated a calculated r value of 0.730 greater than the critical r value of 0.088 at 0.05 level of significance ($p<0.001$). The result indicated that, Entrepreneurship Education has significant impact on poverty reduction. Therefore, the null hypothesis which states that, there is no significant impact between Entrepreneurship Education and poverty reduction for national development in Nigeria was rejected.

Objective 3: What are the strategies for enhancing Entrepreneurship Education toward National Development?

Table 5
The Extent to what are the Strategies for Enhancing Entrepreneurship Education for National Development

S/N	Items	Agree	Disagree	X	SD
1	Provision of funds by Government, financial institution and NGO's	182	10	3.6	1.8
2	Provision of interest free loan to start up business	176	16	3.5	1.7
3	Establishment of centers for Entrepreneurship development	179	13	3.5	1.7
4	Provision of conducive environment and facilities for teaching and learning of Entrepreneurship Education	169	23	3.4	1.6
	Grand Mean			**3.5**	**1.7**

Source: field Survey, 2023

Table 5 answered research question three on what are the strategies for enhancing Entrepreneurship Education toward National Development. The table revealed that, Provision of funds by Government, financial institution and NGO's, provision of interest free loan to start up business, establishment of centers for Entrepreneurship development and provision of conducive environment and facilities for teaching and learning of Entrepreneurship Education will enhance Entrepreneurship Education for national development. This is because the mean score (3.6, 3.5, 3.5, and 3.4 respectively) with grand mean 3.5, is greater than the 2.5 bench mark for agreement.

Discussion of Findings

The results of this study indicated that, Entrepreneurship Education has significant effect on job creation for national development. This finding as revealed in table 1 indicated that, majority of respondents (132) agreed that, Entrepreneurship Education has significant effect on job creation. Since the calculated mean score of the respondents was 2.8 greater than the 2.5 bench mark for agreement, the researchers concluded that, respondents agreed with the notion that, entrepreneurship Education has significant effect on job creation for national development. The results on table 4 further revealed that, the effect of entrepreneurship education on job creation was statistically significant. Regression analysis indicated that, r-calculated (0.739) was greater than r-critical (0.088) at 0.05 level of significance ($p<0.001$). This finding was in line with Kamar et al, (2021) opined that entrepreneurship education plays a significant role in changing students' view towards becoming self-employed. This is because entrepreneurship education is meant to train students upon graduation to become self-reliant and employers of labour through creative and innovative thinking in identifying new business opportunities.

The study also found that, Entrepreneurship Education has significant impact on poverty reduction for national development. This finding as revealed in table 2 indicated that, majority of respondents (129) agreed that, Entrepreneurship Education has significant impact on poverty reduction. Since the calculated mean score of the respondents was 2.7 greater than the 2.5 bench mark for agreement, the researchers concluded that, entrepreneurship Education has significant impact on poverty reduction for national development. The results on table 5 further revealed that, the impact of entrepreneurship education on job creation was statistically significant. Regression analysis indicated that, r calculated (0.730) was greater than r-critical (0.088) at 0.05 level of significance ($p<0.001$). This finding was in line with Ifeoma et al, (2018) claimed that Entrepreneurship development is a key tool for poverty reduction; stimulating employment and economic growth in developing countries. Usman and Adam (2017) posited that a significant positive relationship was found to exist between entrepreneurship and poverty reduction.

The study also revealed that, Provision of funds by Government, financial institution and NGO's, provision of interest free loan to start up business, establishment of centers for Entrepreneurship development and provision of conducive environment and facilities for teaching and learning of Entrepreneurship Education will enhance Entrepreneurship Education for national development.

Conclusion

Based on the findings of the study, the following conclusions were drawn:

I. Entrepreneurship Education has significant effect on job creation and poverty reduction for national development.
II. Provision of funds by Government, financial institution and NGO's, provision of interest free loan to start up business, establishment of centers for Entrepreneurship development and provision of conducive environment and facilities for teaching and learning of Entrepreneurship Education will enhance Entrepreneurship Education for national development.

Recommendations

Based on the findings and conclusion of the study, the following recommendations were made by the researchers;

I. Center for entrepreneurship education should be established in every tertiary institution while undergraduate students should be mandated to go for internship skill acquisition.

II. Government should increase the budgetary allocation and provide soft free interest loan to graduating students to start their businesses. In addition, the institutions should ensure the provision of appropriate instructional materials and equipment for job creation and poverty reduction for national development.

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SUB-THEME 2

Sustainable and Safe Food Systems, Biotechnology and Climate-Smart Agriculture for Healthier Diets

Despite world food production keeping pace with population growth because of the Green Revolution, the United Nations State of Food Security and Nutrition in the World 2022 Report indicates that the number of people affected by hunger has increased with 29.3% of the global population food insecure, and 22% of children under five years of age stunted. Many more have low-quality, unhealthy diets and micro-nutrient deficiencies leading to obesity, diabetes, and other diet-related non-communicable diseases. Food safety and nutrition are inextricably linked. To achieve optimal human health and wellbeing, people must be both well-nourished and free from foodborne diseases. Additionally, current agro-food systems significantly impact the environment, including soil and water resources. Food systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries. Climate change has negatively impacted on production by reducing crop yields, nutritional quality and lowering livestock productivity. Climate-smart agriculture is an integrated approach that aims at increasing productivity, enhancing resilience and reducing greenhouse gas emissions. Biotechnology through genetic engineering offers methods to improve food and nutritional security by raising the quality and yield of crops. Research and development on sustainable practices and solutions are required for achieving food and nutritional security while protecting the natural resources. Therefore, this sub-theme calls for abstracts, papers and posters that focus on how research and innovation can support the use of sustainable and safe food systems, biotechnology and climate-smart agriculture for enhanced food security.

Identification of Grey Leaf Spot Resistance in F2 Maize (Zea Mays L.) Populations using Simple Sequence Repeat Markers (SSR)

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Abstract

Maize (*Zea mays* L.) is an important cereal crop worldwide especially in Sub-Saharan Africa. The yields of maize are, however, relatively low in Kenya largely due to foliar disease that significantly led to inconsistencies in productivity of maize genotypes in various environments. Identification and utilization of disease resistance mechanism and development of resistant cultivars is crucial in disease management. The objective of the study was to identify SSR markers linked to GLS resistance genes among the selected F_2 population. A total of 23 genotypes were selected based on their disease severity in the field. Initially these genotypes were selected from a group of 20 F_2, 9 parents and two checks resistant (R) and susceptible (S) to GLS. Symptomatic fresh leaves were used in the extraction of genomic deoxyribonucleic acid (DNA) and amplification done using markers linked to grey leaf spot disease. A total of four SSR markers were screened for polymorphism among the resistant F_2 population. Among, the four SSR markers (Cpr1-117757, Bnlg 1258**,** Bnlg 1194, and Phi 031) only one primer (Cpr1-117757) was found to be polymorphic and they were used for finding out resistant gene harbouring plants. The banding pattern of all screened genotypes were scored as either present (+) or absent (-) of the targeted resistant gene. Thirteen F_2 population (CKDHL 120312/CKL 05017, CKL 15537/CML 568, CKDHL 120312/$S_5$96-15-1-1, KTLN 10123/$S_5$96-15-1-1, CKL 05022/$S_5$96-15-1-1, CKDHL 153502/$S_5$96-15-1-1, CKDHL 120312/CML 395, CKL 05022/ CML 395, CKDHL 153502/CML 395, CKL 15537/CML 395, CKL 05022/CKL 05017, CKL 15537/CKL 05017 and CKDHL 153502/CML 568), eight parents (CKDHL 12312, KTLN 10123, CKL 05022, CKDHL 153502, CKL 05017, CML 568, $S_5$96-15-1-1 and CML 395) and two commercial checks (H512 and H614) which were categorized as the resistance and moderately resistance genotypes under artificial inoculation revealed different banding patterns. The information provided by the identified marker would be very useful in breeding programs to select maize genotypes harbouring GLS resistance genes.

Keywords: Germplasm, GLS, Polymorphism, Segregating and SSR

1.0 Introduction

In rural and urban households in Kenya, maize has become a significant crop in many families because of its potential as a source of dietary fibre, protein and phytochemical compounds and hence contribution to nutritional security (Galani *et al.*, 2022). The inheritance of grey leaf spot is a complex trait controlled by multiple genes with additive effect (Kuki *et al*., 2018). It is challenging to improve complex traits which are influenced by environment through conventional breeding, but the use of molecular markers enhances and fasten the selection process although it

requires efficient field screening so as to relate phenotypic characteristics with DNA variations. Quantitative trait loci (QTL) for GLS resistance have emerged as effective method of identifying candidate genes governing the traits to be selected in crops (Sun *et al*., 2021a). The identification of SSR markers linked to disease resistant is crucial, therefore, for understanding the molecular basis of these traits quite important in future breeding.

Marker assisted selection (MAS) for selection of genes linked to a specified trait with measurable differences is an important technique in molecular breeding. The technique is used for measuring effect of complex traits linked to a specific genomic region (Maloy & Hughes, 2013). In comparison to GWAS and QTLs studies, MAS have the advantage of utilizing few numbers of lines that need to be tested. Since many lines can be discarded after MAS at an early generation, this permits a more effective breeding design (Hasan *et al*., 2021). Effectiveness of marker assisted selection depends on molecular marker to be used, thus significant progress in crop disease resistance breeding has been achieved by MAS. However, the study of GLS resistance on maize using SSR markers has not been widely documented.

Different methods have been used for screening for GLS resistance under laboratory, greenhouse and field environments. Laboratory is the most important method because it saves time and cost. Marker-assisted selections, molecular analysis, linkage Mapping, and selective phenotyping can be utilized in modern laboratories (Kuki *et al.,* 2018b; Kibe *et al.,* 2020a). Using molecular marker systems, genomic regions responsible for GLS resistance with specified marker can be located. molecular breeding techniques allows rapid identification of markers, for trait mapping in plant breeding. This is a sole proofs on the molecular analysis available in crops (Nyanapah *et al.,* 2022). Genetic mapping and genome-wide association has been done using single- nucleotide polymorphism (SNP) markers (Sun *et al*., 2021b). Combining molecular analysis with field screening can be the most effective and reliable breeding method than the use of field screening alone in identification of important traits in crop improvement.

Studies of molecular analysis using SSR markers related to grey leaf spot resistance in maize are limited. According to Omondi, (2022) and Du *et al*, (2020c), quantitative trait loci (QTLs) closely linked with *qGLS_YZ2-1* region and GLS resistance using SSR markers has been done. However, molecular analysis using marker assisted selection (MAS) in GLS breeding in maize improvement in Kenya and markers specific to GLS are scarcely researched up to date.

2.0 Materials and methods

2.1 Plant materials

A total of 23 (table 1) maize germplasm, from previous screening and selection across three environments representing parents, F_2 populations and the commercial checks were selected for molecular analysis. Each of the genotypes was grown at the University of Eldoret, glass house in three replicates (0°37'N and 35°15'E, approximately 2,143 m. a. s. l.). The mean maximum and minimum temperatures were 26 and 10 ^{0}C.

Table 1: Maize germplasm used in the study

CODE	GENOTYPES	CLASSIFICATION
G1	CKDHL 120312/CKL 05017	R
G10	CKL 15537/CML 568	MR
G11	CKDHL 120312/S5 96-15-1-1	R
G12	KTLN 10123/S5 96-15-1-1	R
G13	CKL 05022/S5 96-15-1-1	R
G14	CKDHL 153502/S596-15-1-1	R
G15	CKL 15537/S5 96-15-1-1	MS
G16	CKDHL 120312/CML 395	R
G17	KTLN 10123/CML 395	MR
G18	CKL 05022/CML 395	R
G19	CKDHL 153502/CML 395	R
G2	KTLN 10123/CKL 05017	MR
G20	CKL 15537/CML 395	MR
G21	H512	R
G22	H614	MR
G23	CKDHL 120312	MR
G24	KTLN 10123	R
G25	CKL 05022	MR
G26	CKDHL 153502	MR
G27	CKL 15537	MR
G28	CKL 05017	MR
G29	CML 568	MR
G3	CKL 05022/CKL 05017	MR

2.2 Deoxyribonucleic acid (DNA) extraction

Total genomic DNA was extracted from 60 days old maize leaves expressing symptoms of grey leaf spot (GLS) harvested from greenhouse plants. The harvested leaves were labelled and immediately put in icebox and taken to the laboratory where they were placed in -80°C for ease of grinding. Prepared Cetyltrimethylammonium bromide (CTAB) and modified protocol as suggested by (Olufemi *et al*. 2008) was used to extract the DNA where 100 mg leaf samples were weighed and crushed to form a homogenous paste in 500 µl CTAB buffer (10% SDS, 0.5 M EDTA, 1 M Tris-HCl with a final pH of 8.0). 10 ul of 100mg/ml RNaseA to remove RNASES was added and the homogenate transferred into 1.5ml Eppendorf tube and incubated at 65 °C water-bath for 30 minutes. The tube was inverted 5-6 times after every five minutes during the extracted sample was then cooled down in fridge for 15 minutes and 200ul of 6M Ammonium Acetate added and vortexed. The mixture was kept in fridge at 4°C for 15 minutes. Using Eppendorf centrifuge, the mixture was centrifuged for 5 minutes at 13000rpm. The supernatant was transferred to a new Eppendorf tube and 50 µl of 10% CTAB preceding addition of 700 ul of chloroform: isoamyl alcohol (24:1) and gently mixed by inversion. The mixture was centrifuged at 13,000g for 5 minutes. The upper phase (approx. 500ul) was transferred to a new Eppendorf tube and DNA precipitated by addition of 350ul ice cold isopropanol, the tubes were gently inverted and kept at -20°C for 15 minutes. The precipitated DNA was pelleted by centrifuging at 14000 rpm for 20 minutes followed by 70% and 90% ethanol washing the pellets. The pellets were air dried on a clean bench and dissolved in 100ul 1x TE (tris EDTA) buffer.

2.3 DNA Quantification

The quality of DNA was determined by running it on 1% agarose gel with 1x TBE buffer (Trizma base with EDTA and boric acid; pH was adjusted to 8.0 with NaOH) at 100 V for 45 minutes. As a check for DNA quality and quantity, all samples from infected genotypes were successfully subjected to quantification using Nanodrop spectrophotometer (ND-2000, UV-Vis spectrophotometer) (Table 2)

Table 2: DNA Concentration of 23 genotypes

Nucleic Acid	Unit	A280 (Abs)	260/280	Sample type	Factor	#
89.9	$ng/\mu l$	3.637	0.49	DNA	50.00	1
77.3	$ng/\mu l$	1.013	1.53	DNA	50.00	2
75.6	$ng/\mu l$	1.235	1.22	DNA	50.00	3
338.9	$ng/\mu l$	3.595	1.89	DNA	50.00	4
48.6	$ng/\mu l$	0.744	1.31	DNA	50.00	5
12.4	$ng/\mu l$	0.237	1.04	DNA	50.00	6
13.9	$ng/\mu l$	0.255	1.09	DNA	50.00	7
74.3	$ng/\mu l$	0.972	1.53	DNA	50.00	8
79.0	$ng/\mu l$	1.041	1.52	DNA	50.00	9
65.7	$ng/\mu l$	0.954	1.38	DNA	50.00	10
113.4	$ng/\mu l$	1.395	1.63	DNA	50.00	11
190.1	$ng/\mu l$	2.372	1.60	DNA	50.00	12
189.9	$ng/\mu l$	2.374	1.60	DNA	50.00	13
178.3	$ng/\mu l$	1.849	1.93	DNA	50.00	14
170.0	$ng/\mu l$	2.497	1.36	DNA	50.00	15
183.2	$ng/\mu l$	2.063	1.78	DNA	50.00	16
99.6	$ng/\mu l$	1.124	1.77	DNA	50.00	17
142.8	$ng/\mu l$	1.530	1.87	DNA	50.00	18
1370.8	$ng/\mu l$	12.893	2.13	DNA	50.00	19
407.6	$ng/\mu l$	4.215	1.93	DNA	50.00	20
36.1	$ng/\mu l$	0.470	1.54	DNA	50.00	21
16.6	$ng/\mu l$	0.258	1.28	DNA	50.00	22
201.2	$ng/\mu l$	2.220	1.88	DNA	50.00	23

2.4 Polymerase chain reaction (PCR) amplification

The extracted DNA was amplified using Eppendorf master cycler gradient PCR. Four SSR primers pairs were selected based on their linkage with grey leaf spot resistance gene. The primer codes and base pairs are shown in table 3.

Table 3: Summary of SSR primers used in the study

SN	Primer	Sequence	Ta ^{0}C
1	Bnlg 1258	F: GGTGAGATCGTCAGGGAAAA	49(53)
		R: GAGAAGGAACCTGATGCTGC	
		TGAACTACGCGCTCAATGGTCCACGAAACAAGTACGA	
2	Cpr1-117757	TTCGACACTCGAACTTCAAGCTCCCCTCAGACCCAAGC	52 (48)
3	Bnlg 1194	F: GCGTTATTAAGGCAAGCTGC	58(52)
		R: ACGTGAAGCAGAGGATCCAT	
4	Phi 031	F: GCAAGAGGTTACATGAGCTCACGA	45(57)
		R: CCAGCGTGCTGTTCCAGTAGTT	

Ta, annealing temperature, Tm, Melting (temperature)

2.4 Visualization of the PCR bands

A 1% Agarose gel was prepared by mixing 1.0 g of Agarose with 100 ml 1x TBE (Tris- HCL Boric Acid EDTA) buffer. The solution was then heated in a microwave for proper mixing. The gel was left to cool to approximately 60°C then 3 µl of nucleic acid gel stain Ethidium Bromide was added. The gel was then cast in trays and combs carefully placed and solidification allowed occurring. The PCR products obtained were then mixed with 1 µl of the loading dye (orange G) and 5µl of the sample loaded in each well. The data on band separation was scored as present (+) or absent (-) for the genes responsible for GLS diseases in maize.

3.0 Results

Detection of the gene linked to GLS disease in maize

Molecular analysis of the resistant gene by SSR markers revealed the present of GLS genes in the resistant genotypes (Table 3). The PCR product of for these genotypes were digested into different fragments with the CPrI-117757, while it remained uncut when treated with BnIg 1258, Bnlg 1194 and Phi 031, suggesting that the GLS gene is located in 164bp and is in homozygous state (Fig. 1), but no amplification was obtained from susceptible genotypes.

Six genotypes possessed the susceptible genes. The gene were grouped into three different clusters due to comparison in disease severity in the field. CKL 05022/S596-15-1-1 and CKDHL 120312/CML 395 were grouped in cluster 1, with high level of resistant, CKDHL 120312/CKL05017, CKDHL 120312/S596-15-1-1, KTLN 10123/S596-15-1-1, CKDHL 153502/S596-15-1-1, CKL 05022/CML 395, CKDHL 153502/CML395 and KTLN 10123 from cluster 2 had severity level of 2, CKL 15537/CML 568, CKL 15537/CML395, CKDHL 120312, CKL 05022, CKDHL 153502, CML 568 and CKL 05022/CKL05017 severity of 3. The susceptible were CKL 15537/S596-15-1-1, KTLN 10123/CML 395, KTLN 10123/CKL05017, CKL 05017 and CKL15537.

Table 4: Presence (+) or absence (-) of resistant genes linked to GLS in 23 screened genotypes

No	Genotypes	GLS Primers				Field data
		CPrI-117757	Bngl 1258	Bnlg 1194	Phi 031	GLS
1	CKDHL 120312/CKL05017	+	-	-	-	2.65
2	CKL 15537/CML 568	+	-	-	-	3.7
3	CKDHL 120312/S596-15-1-1	+	-	-	-	2.55
4	KTLN 10123/S596-15-1-1	+	-	-	-	2.25
5	CKL 05022/S596-15-1-1	+	-	-	-	1.85
6	CKDHL 153502/S596-15-1-1	+	-	-	-	2.72
7	CKL 15537/S596-15-1-1	-	-	-	-	5.77
8	H614	-	-	-	-	5.28
9	CKDHL 120312/CML 395	+	-	-	-	1.83
10	KTLN 10123/CML 395	-	-	-	-	4.42
11	CKL 05022/CML 395	+	-	-	-	2.52
12	CKDHL 153502/CML395	+	-	-	-	2.38
13	KTLN 10123/CKL05017	-	-	-	-	4.53
14	CKL 15537/CML395	+	-	-	-	3.65
15	H512	+	-	-	-	2.78
16	CKL 05017	-	-	-	-	4.25
17	CKDHL 120312	+	-	-	-	3.22
18	KTLN 10123	+	-	-	-	2.65
19	CKL 05022	+	-	-	-	3.22
20	CKDHL 153502	+	-	-	-	3.83
21	CKL15537	-	-	-	-	4.35
22	CML 568	+	-	-	-	3.37
23	CKL 05022/CKL05017	+	-	-	-	3.77

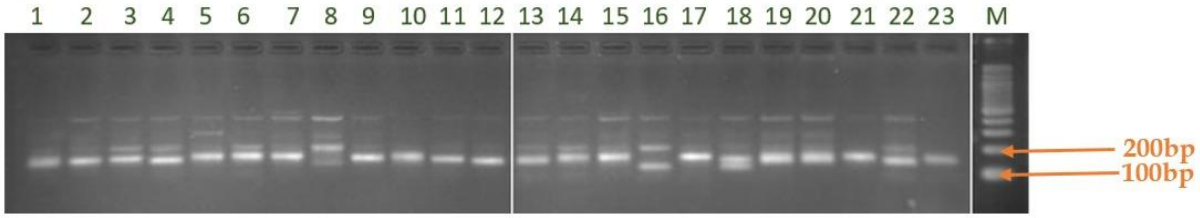

Figure 1: SSR marker for identification of GLS resistant gene among maize genotypes alongside two checks, resistant (H512) and susceptible (H614) commercial hybrids.

Based on SSR analysis, the specific resistant gene for grey leaf spot in maize among the 23 genotypes was located at 164bp (Fig 1). Therefore, six genotypes did not express the presence of resistant gene with the remaining three primers; hence it was classified as absent (-) of the resistant gene (Table 4). The three primers for GLS (Bngl 1258, Bnlg 1194 and Phi 031) did not detect any genes for grey leaf spot disease across all the genotypes and their respective parental lines. However, the CPrI 117757 primer detected the presence of genes linked to grey leaf spot in almost

all the genotypes selected except genotypes CKL 15537/S596-15-1-1, KTLN 10123/CML 395, KTLN 10123/CKL 05017, CKL 05017 and CKL 15537. The banding pattern for all the 20 genotypes showed the presence of resistance GLS genes as well as the parental resistant check (H512).

4.0 Discussion

Knowledge about molecular breeding and technology in crops especially breeding disease resistant genotypes is critical for genotypes utilization, and variety development. The primary goal of any variety development and crop improvement program is to target grain yield and yield components, but breeding for disease resistant, fodder quantity and quality and other traits of economic is equally important. To achieve this balance, any breeding program needs to have gene pool where sufficient genotypes recombination is being created for future references. Creating this gene pool requires mixed genotypes that have potential characteristic of fulfilling farmer's interest. Combination of both molecular analysis and field morphological data have been reported extensively in maize breeding (Gedil & Menkir, 2019), similarly, the current study give insights of the importance of the two analyses.

The results obtained from this study show resistant genotypes among evaluated F_1 generation and their parents in GLS resistance. These results suggest that some of the genotypes have the resistant gene located at 164bp which is in concurrence with earlier studies that conventional and quantitative PCR produced a 164 bp fragment in *Cercospora zeae-maydis* isolates (Korsman *et al*., 2012). Also, field data on disease severity corresponded with the molecular data that all resistant genotypes at the field had the resistant gene. Therefore, this information could be used as a base for the development of varieties that have resistance in disease pressured environments. The cross between genotype KTLN 10123 which was rated as the most resistant parent and S_5 96-15-1-1 which was moderately resistant at the field produced among the most resistant combination in the field and confirmed during molecular analysis, this study was similar with the report by Dhami *et al*. (2015), who reported that crosses between resistant and the most susceptible lines resulted in resistant hybrids due to the predominance of additive nature of gene actions and major dominant effects of some genes.

Any successful maize breeders require a stable resistance variety against grey leaf spot. Conventionally, breeders have relied on the resistant hybrids from Kenya seed company, however, with time, these hybrids have been compromised by GLS disease because of environment fluctuation. Therefore, resistant gene located in 164bp become important resistance source to many breeders in Kenya. Currently, quantitative trait loci (QTLs) has been successfully employed in the development of resistance varieties (Benson *et al*., 2015). Furthermore, study on GWAS on GLS resistance maize has been done (Hu *et al*., 2024a ; Nyanapah *et al*., 2022 ; Zhu *et al*., 2021). However, location of the gene responsible for GLS resistance using molecular markers has proven a reliable approach to accelerate the breeding process. Currently, several markers linked to this locus are available for screening maize genotypes (Korsman *et al.*, 2012), however, their efficacy for identifying resistance gene needs to be evaluated more rigorously. Earlier reported studies seeking resistance against GLS have shown that the SSR markers have high specificity than other markers (Qiu *et al.*, 2021). Reliability and high level of polymorphism of the SSR markers in investigated germplasm will reduce the tracking of resistance genes during the selection process and speed up the breeding cycle.

In the current study, among the resistant genes, genotypes CKDHL 120312/CML 395 and CKL 05022/S_5 96-15-1-1 were the leading. and these genotypes were combination of different maize lines. These genotypes can be used as sources of resistance genes especially in combination of high yielding varieties.

5.0 Conclusion

The results of this study provide a more thorough and higher-resolution understanding of the molecular analysis of GLS resistance and provide initial support about gene responsible for resistance to GLS in maize. Plant breeding decisions regarding development and deployment of resistance will accelerate the breeding cycle if only there is better understanding of the molecular breeding for disease resistance.

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Striga (*Striga Hermonthica* (Del.) Benth) Tolerance in Maseno EH11 and EH14 Hybrid Maize Varieties

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Abstract

Striga (*Striga hermonthica* (Del.) Benth) is an obligate root hemi-parasitic weed parasitizing maize (*Zea mays* L.) and other grasses causing significant losses. Two newly released hybrid maize varieties Maseno EH11 and EH14 have been bred for tolerance to Striga but their extent and mechanism of tolerance have not been elucidated. Field experiments were carried out in Western Kenya at Kibos, Nyahera and Maseno for two seasons under natural Striga infestation to determine their level of tolerance to Striga alongside a Striga susceptible PHB3253 variety and two local checks, H513 and H516. The new maize varieties were later grown in rhizotrons where the roots were infected with pre-germinated Striga seeds and histological studies carried out to determine the extent of Striga attachment at 9 days after infection. The field data included days to Striga emergence, Striga incidence and crop growth and yield. The number, length and biomass of attached Striga in the rhizotrons were determined. Data was subjected to ANOVA through the general linear model of SAS and means separated using $LSD_{0.05}$. Maseno EH14 took the longest time for Striga to emerge in the field, exhibited few Striga attachments across the seasons and had the highest 100-grain weight. Maseno EH14 also exhibited few and shorter Striga attachments in the rhizotrons. Histological analysis showed that most Striga haustoria were unable to penetrate the endodermis of Maseno EH14 while PHB3253 and Maseno EH11 had successful parasite-host xylem to xylem vascular connections although EH11 had few cases of tolerance response similar to EH14. From these findings, Maseno EH14 has Striga tolerance which could be attributed to mechanical processes occurring at the cell wall thus becoming a good source of genetic material for the development of sustainable management of Striga and could provide genes leading to development of maize varieties with host-based resistance.

Key words: *Maize, Striga, tolerance and infestation*

Introduction

Purple witchweed (*Striga hermonthica* (Del.) Benth) is an obligate root hemi-parasitic plant that attacks several cereal grains in the poaceae family especially maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) and other native and exotic grasses throughout Africa (Berner *et al.,* 1995). It causes yield losses ranging from 20 – 80% although this could go up to 100% in susceptible cultivars under high levels of infestation (Teka, 2014). This translates to more than US $ 7 billion annually affecting the livelihoods of more than 300 million people living in sub-Saharan Africa (Ejeta, 2007).

Maize (*Zea mays* L.) is an important cereal grain providing nearly half of human calorific requirements. It therefore has a big potential in terms of its large utilization as a food and animal feed source (Farnia and Mansouri, 2015). In Kenya, maize is the main staple food with the consumption estimated at 98 kg per person per year translating to 30 – 40 million bags per year, and accounts for 36% of all calories consumed (Nyoro *et al.,* 2004). It therefore forms an important component of household food security within the Kenyan farm families and any threat to maize is a serious threat to food security. Maize yields in Western Kenya average 2.5 t ha^{-1} (Davenport *et al.,* 2018) against the world's average yield of 5.5 t ha^{-1} (Adnan *et al.,* 2017). The low yields is majorly attributed to the parasitic *Striga* weed amongst other factors like declining soil fertility (Odendo *et al.,* 2001). Maize is exceptionally susceptible to *Striga* infestations, especially in marginal areas characterized by sub-optimal soil nitrogen conditions (Menkir *et al.,* 2012, Ejeta, 2007). The infestation level is more severe in areas with poor soil fertility, low rainfall, and lack of fertilizer use (Sauerborn *et al.,* 2003).

The management of *Striga* has become quite challenging owing to its production of large amounts of tiny seeds that persist in the soil for long periods (Yoneyama *et al.,* 2010, Rich and Ejeta, 2008 and Westerman *et al.,* 2018). This therefore calls for a combination of several management options in an integrated approach. The use of improved crop varieties with resistance to *Striga* is a feasible option, especially for the resource-poor farmers (Rich and Ejeta 2008). Kamara *et al.* 2020 also observed that the use of *Striga*-resistant maize varieties combined with the application of nitrogen fertilizer and rotation with soybean could increase the productivity of maize in *Striga* infested fields. This study was carried out to determine the relative performance in *Striga* tolerance and *Striga* tolerance mechanisms of Maseno EH14 which has been bred for *Striga* tolerance and Maseno EH11 which has been bred for tolerance to foliar diseases including maize streak virus, grey leaf spot and turcicum leaf blight (Kephis 2020) but has related parents to Maseno EH14. The evaluation was done alongside PHB3253 which is a *Striga* susceptible maize variety (Yoneyama *et al.,* 2015) from Pioneer Hybrid Company (Kephis 2020), and two locally grown hybrid maize varieties from Kenya Seed Company namely H513 and H516 as the check varieties. This study was carried out in the field under natural *Striga* infestation and a non-infested field.

Materials and Methods

Field Experiments

Field trials were conducted in the short rains of 2020 (SR2020) and long rains of 2021 (LR2021) at two *Striga*-infested fields at KESREF – Kibos (-0.03861°S, 34.81596°E) and a farmer's field in Nyahera (0°35.977'N, 34°53.452'E) and a *Striga* free field at Maseno University (0°00'08S, 34°35'47E), all within Kisumu County of Kenya. The seeds of Maseno EH11 and EH14 hybrid maize varieties were obtained from Maseno University seed unit while the seeds of the check varieties (H513, H516, and PHB3253) were obtained from the local seed stockists. The experiments therefore consisted of the five maize varieties and the treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications. Soil samples were collected from every experimental unit to characterize the initial *Striga* seed bank.

The maize seeds were sown at a spacing of 75cm×25cm with two seeds per hole and later thinned to one plant per hill giving four rows of maize plants each 4m in length. Tripple supper phosphate was applied during planting at the rate of 60 kg P_2O_5 ha^{-1} and topdressed at 6^{th} week after planting with Calcium Ammonium Nitrate at the rate of 60 kg N ha^{-1}. Weeding was done three weeks after

planting but before *Striga* emergence by hand hoeing and thereafter hand pulling was done to remove other weeds to facilitate observation of emerged *Striga* plants. Data was collected from the net plot area of 6 m^2 which consisted of two middle maize rows. The parameters observed included days to first *Striga* emergence which was recorded as the number of days from crop emergence to the date of the first observed emerged *Striga* in the respective experimental plots determined by observing a small whitish protrusion above the ground. *Striga* incidence was recorded at 8, 10 and 12 weeks after crop emergence (WAE) by counting the number of emerged *Striga* plants from the net plot area which were then expressed as plants m^{-1}. The data was log-transformed due to the high variability in numbers as a result of the differences between experimental units and the locations to normalize the variability. Maize growth and yield parameters included plant height which was recorded once as the distance from the base of the plant to the point of the first tassel branch. Days to tasseling were taken as the number of days from crop emergence to the date when 50% of the plants in the net plot had started tasseling. Maize grain yield was determined by shelling the grains from the dried cobs and getting the total grain weight using an electronic weighing balance and the moisture content was determined using a moisture meter. The yield was then adjusted to 12.5% moisture content and then converted to t ha^{-1}. The 100-seed weight was determined by randomly selecting 100 seeds from the dried shelled grains and weighing using an electronic weighing balance. The data collected was subjected to analysis of variance (ANOVA) using the General Linear Model procedure of Statistical Analysis Software (SAS v. 9.1, SAS Institute, Cary, NC, USA) to test if there were significant differences between the treatment means. The means were separated using the Least Significant Difference (LSD) method at 5% probability level. Correlation analysis was done to compare the relationships between the *Striga* parameters and the maize growth and yield components.

Rhizotron Studies

Maseno EH11, Maseno EH14, and the most *Striga* susceptible maize variety (PHB3253) from the field results were screened for post-attachment *Striga* response. The *Striga hermonthica* seeds collected in 2020 from maize growing fields in Kibos Kenya (-0.03861°S, 34.81596°E) were used for the study. The maize seeds were first germinated in 10 cm by 10 cm by 10 cm pots filled with vermiculite. At 7 days after planting, the maize seedlings were transferred to root observation chambers called rhizotrons (25 cm by 25 cm by 5 cm Perspex plates) as described by Mbuvi *et al*. (2017). The rhizotron chambers were lined with 25 cm by 5 cm by 5 cm foam strips at the bottom to absorb excess water and packed with vermiculite. A 50-micron thick mesh was then placed on top, the germinated maize seedlings were placed on the mesh, the chamber closed, and then wrapped with aluminum foil. The maize plants were then maintained in the glasshouse at 60% relative humidity and a 12-hour photoperiod. The day and night temperatures were set at 28°C and 24°C respectively. During growth on the rhizotrons, the plants were drip-irrigated with 25 ml of 40% Long Ashton nutrient solution. After 10 days on the rhizotrons, the maize seedlings with well developed roots were infected with 25 mg of pre-germinated *Striga hermonthica* seeds per plant by aligning the *Striga* seeds along the maize roots with a soft paint brush. Five plants per maize variety were screened in a Completely Randomized Design with three replications.

The rhizotrons containing the infected maize roots were screened at 9 and 21 days after infection (DAI). At 9 DAI, the *Striga* seedlings attached on the maize roots were observed and documented using a Leica MZ7F stereomicroscope fitted with a DFC320FX camera (Leico, Germany). At 21 DAI, all the *Striga* plants attached to the maize roots were harvested, placed on 90-mm petri plates, and photographed to be screened for post-attachment response and to establish the effects of the

host plants on the parasite development. The number and length of the *Striga* seedlings parasitizing each host plant were determined from the photographs using the image analysis software ImageJ, v. 1.45 (http://rsb.info.nih.gov/ij/) according to Mbuvi *et al*. (2017). The *Striga* seedlings were then harvested, oven-dried at 45°C for seven days and weighed according to Mutinda *et al*. (2018) to determine the total *Striga* biomass attached on the maize roots. The data collected on *Striga* numbers, length, and total biomass was subjected to analysis of variance (ANOVA) using the General Linear Model procedure of Statistical Analysis Software (SAS v. 9.1, SAS Institute, Cary, NC, USA). The means were separated using the Least Significant Difference (LSD) method at 5% probability level and presented as box plots generated in R software.

Histological Analysis

Root tissue at the point of the *Striga* haustoria attachment was dissected from the host plants at 9 DAI to determine the extent of parasite development within the host root cortex through sectioning. Five rhizotrons were sampled for each maize variety from which 3 attachments were collected from each rhizotron giving 15 samples for every variety. The tissues were fixed using Carnoy's fixative (4:1, ethanol:acetic acid) then dehydrated twice in 100% ethanol for 30 minutes before pre-infiltration in ethanol-Technovit solution (1:1) for 2 hours then in 100% Technovit solution for another 1 hour. The tissues were then incubated in fresh Technovit solution for 3 days at 4°C. For purposes of embedding, the samples were placed in Eppendorf lid molds containing Technovit-Hardener (1:15) and left to set. The embedded tissues were then mounted on wooden blocks using the Technovit 3040 kit according to the manufacturer's instructions. 5-micron thick sections were obtained using a Leica RM 2145 microtome (Leica, Germany) which were then transferred to microscope slides. They were stained using 0.1% toluidine blue O in 100 mM phosphate buffer at pH 7 for 2 minutes then washed in distilled water and dried at 65°C for 30 minutes on a hot plate. The sections were then mounted on glass slides and covered with slips using DePex (BDH, Poole, UK) before being observed and photographed using a Leica DM500 microscope mounted with a Leica ICC50 camera (Leica, Germany).

Results

The initial count of the *Striga* seed bank which was done before field evaluation across all the locations did not show any significant differences with respect to the maize varieties assigned to each experimental unit. The growing seasons did not have a significant effect on the days to *Striga* emergence (Table i). However, the locations significantly affected the days to *Striga* emergence ($P \leq 0.0001$) with Nyahera taking 42.9 days from crop emergence to *Striga* emergence while Kibos took 62.3 days. There was no *Striga* observed in the *Striga* free field. The maize varieties also significantly affected the duration of *Striga* emergence ($P \leq 0.01$) with the *Striga* susceptible maize variety, PHB3253 taking 47 days from crop emergence to the first observed *Striga* while the *Striga* tolerant maize variety, Maseno EH14 took 61.3 days (Table ii). Maseno EH11 did not differ significantly from Maseno EH14 and the local check varieties H513 and H516. The two local check varieties did not differ significantly from the *Striga* susceptible maize variety PHB3253.

The *Striga* counts were done at Kibos and Nyahera locations for the two seasons and the cumulative count per square metre was then computed by adding the counts of the three stages. The locations significantly affected the *Striga* incidence ($P \leq 0.0001$) right from 8 WAE to 12 WAE. The effect was also observed in the cumulative *Striga* count as shown in Table i. Nyahera had significantly higher *Striga* counts than Kibos from 8 WAE to 12 WAE with a cumulative count (CUMC) of 66.1 plants m^{-2} compared to 6.8 plants m^{-2} at Kibos (Fig. 1). Maize varieties

significantly influenced the *Striga* counts (P≤0.0001) from 8 WAE all through to 12 WAE (Table iii). The *Striga* susceptible maize variety PHB3253 had 12.8 *Striga* plants m^{-2} at 8 WAE which was not different from the local check varieties H513 and H516. Similarly, Maseno EH14 had 0.43 *Striga* plants m^{-2} which also did not differ significantly from the Maseno EH11 variety. The same trend was maintained all through to 12 WAE with the *Striga* susceptible maize variety PHB3253 having significantly higher *Striga* counts while Maseno EH14 and Maseno EH11 had significantly lower *Striga* counts (Table iii). The interaction of location and maize varieties significantly (P≤0.0001) affected the *Striga* counts in all three stages of counting as shown in Figure 2. While the *Striga* tolerant maize variety, Maseno EH14 and Maseno EH11 did not have significant differences in *Striga* counts at the two *Striga* infested locations, the *Striga* susceptible maize variety PHB3253 and the two local check varieties H513 and H516 had significantly higher counts in Nyahera than in Kibos.

The maize growth and yield parameters were evaluated across the seasons for both the *Striga* infested locations and the non-infested site (Maseno University research field). The effect of the locations was highly significant (P≤0.0001) on all the four parameters: plant height, days to tasseling, maize yield, and 100 seed weight (Table iv). The maize plants at Maseno took significantly higher number of days to tasseling at 66.7 days while Kibos took the lowest number of days to tasseling at 60.6 days (Table v). In terms of plant height, Kibos had the tallest plants at 225.95 cm although this did not significantly differ from the maize plants at Maseno. However, Nyahera had significantly shorter plants at 150.97 cm. Maseno which was the *Striga*-free location had significantly higher maize yields at 3.72 t ha^{-1} although this did not significantly differ from the maize yield at Kibos. However, Nyahera had significantly lower maize yields at 2 t ha^{-1}. The highest significant grain weight in terms of 100 seed weight was 26.62 g at Kibos and the lowest was 19.37 g at Nyahera. The effect of maize varieties on the number of days from crop emergence to tasseling was highly significant (P≤0.0001) with the *Striga* tolerant maize variety, Maseno EH14 taking the highest number of days to tasseling across all the locations at 65.8 days while the local check varieties H516 and H513 took significantly shorter days to tasseling at 61.9 and 61 days respectively. There was however no significant difference between the *Striga* susceptible maize variety PHB3253 and the disease tolerant maize variety Maseno EH11 on their effect on the number of days to tasseling as shown in Table (vi).

Maize varieties also significantly affected the plant height (P≤0.025). Maseno EH14 and Maseno EH11 were taller plants at 207.56 cm and 207.89 cm, respectively however, their heights did not differ from the two local checks. The *Striga* susceptible maize variety PHB3253 was shorter among the rest at 185.17 cm although it also did not significantly differ from H516 and H513 (Table vi). The overall maize yield across the locations was not affected by the maize varieties but the yield trend per location was visibly different at Nyahera which had higher *Striga* counts (Fig 3). Maize varieties however, had significant effects (P≤0.01) on the 100 seed weight with the *Striga* tolerant maize variety Maseno EH14 having a significantly higher seed weight of 24.81 g although this did not significantly differ from Maseno EH11 and the local check variety H513. The *Striga* susceptible maize variety PHB3253 had a significantly lower seed weight across the locations at 21.39 g.

Correlation Analysis

The pearson's correlation analysis revealed significant negative correlations between plant height and *Striga* count at 8 WAE (r = -0.778**), *Striga* count at 10 WAE (r = -0.7782**), *Striga* count

at 12 WAE (r = -0.781**) and the cumulative *Striga* count (r = -0.781**). There were also significant negative correlations between days to *Striga* emergence and *Striga* count at 8 WAE (r = -0.8371**), *Striga* count at 10 WAE (r = -0.8395**), *Striga* count at 12 WAE (r = -0.8427**) and the cumulative *Striga* count (r = -0.8429**). The other significant negative correlations included *Striga* count at 8 WAE and the total grain weight (r = -0.7501**), *Striga* count at 8 WAE and 100 seed weight (r = -0.7309*), *Striga* count at 10 WAE and total grain weight (r = -0.7584**), *Striga* count at 10 WAE and 100 seed weight (r = -0.7479**), *Striga* count at 12 WAE and grain weight (r = -0.7444**), *Striga* count at 12 WAE and 100 seed weight (r = -0.7478**), cumulative *Striga* count and grain weight (r = -0.7526**) and cumulative *Striga* count and 100 seed weight (r = -0.7466**) as shown in Table vii below. The notable significant positive correlations included days to *Striga* emergence and plant height (r = 0.9334***), days to *Striga* emergence and total grain weight (r = 0.8422**), days to *Striga* emergence and 100 seed weight (r = 0.8793**), plant height and total grain weight (r = 0.8612**), plant height and 100 seed weight (r = 0.9533**) and finally the total grain weight and 100 seed weight (r = 0.8941***)

Post-Attachment Response

Three main parameters used to determine the post-attachment response of the maize hybrids to *Striga* parasitism were the number of attached *Striga*, *Striga* length and the biomass of *Striga* attachments. Mutinda *et al.,* 2018 observed that *Striga* resistance is measured by the number of successful parasites infecting a host in the root observation chambers – rhizotrons where resistance response was characterized by fewer, smaller, and less biomass relative to a susceptible host. Our results indicated that Maseno EH14 suffered notably low infestation compared to EH11 and PHB3253 (Fig. 4). There were statistical differences ($P \leq 0.005$) in the number of *Striga* attachments with the susceptible variety PHB3253 having the highest mean number of attachments (55.3±0.75) although this did not differ from Maseno EH11 (Fig. 5). Similarly, the length of the attached *Striga* seedlings in PHB3253 were longer (5.47±0.04 mm) than those attached to Maseno EH14 (3.28±0.22 mm) (Fig.6). The biomass of the attached *Striga* seedlings also showed significant differences ($P \leq 0.0001$) where PHB3253 had the highest *Striga* biomass (18.37±0.32 mg), followed by EH11 (15.94±0.62 mg) and a lower biomass for Maseno EH14 (5.18±0.74 mg) (Fig. 7)

Discussion

Different maize varieties exhibit varied responses to *Striga* parasitism which is reflected in their growth and yield performances. Maseno EH14 and Maseno EH11 hybrid maize varieties both exhibited delayed emergence of *Striga* in the field with a significant difference of about two weeks from that of the *Striga* susceptible variety PHB3253 (Table ii). This could have been necessitated by resistance of the host's roots to *Striga* haustorial penetration leading to slow establishment of successful parasite-host relationship. Van Ast *et al*., 2000 observed that slight differences in the disturbance of plant growth in the initial phases by parasite attachment have a large influence on the final level of yield reduction. After successful attachment, the developing *Striga* plants grow underground for 4 – 7 weeks prior to emergence (Berner *et al*. 1995) translating into 28 - 49 days. This therefore means that the susceptible variety PHB3253 with a mean days to *Striga* emergence of 47 had an immediate *Striga* attachment after maize seed germination. This therefore means that early attachment of *Striga* has a greater effect on the growth of its host compared to late attachments. This was further supported by the pearson's correlation analysis which indicated a significant strong positive relationship between days to *Striga* emergence and maize yield and 100 seed weight (Table vii). Early or late *Striga* attachments translate to early or late *Striga* emergence

respectively. The early *Striga* emergence therefore impose a serious disturbance on the host's dry matter partitioning subsequently leading to a reduction in the maize yield.

The *Striga* counts exhibited locational differences with Nyahera having higher *Striga* counts than Kibos (Figure 1). However, the differences were only observed on the susceptible check varieties while Maseno EH11 and EH14 did not exhibit differences in *Striga* counts (Figure 2). This shows that these two maize varieties were able to outmaneuver *Striga* parasitism despite the level of infestation. This was reflected in the maize yield differences in the three locations (Figure 3). Both Maseno EH14 and EH11 exhibited significantly low *Striga* counts compared to the three check varieties (Table 3). This further implies that the apparent difficulty of the haustoria to penetrate the host's cell layers led to low *Striga* incidence in EH14 and EH11 maize varieties compared to the susceptible PHB3253 and the other two check varieties. The many *Striga* plants attached to the susceptible varieties at an early stage of their life cycle siphon water and nutrients from the hosts leading to exposure to nutrient stress. Exposing the host plants to nutrient stress leads to a decrease in growth rate and change in biomass portioning and nutrient distribution as observed by Sun *et al*., 2011. This explains the strong negative correlations between the *Striga* counts (8 WAE, 10 WAE, 12 WAE, CUMC) and the maize yield and 100 seed weight (Table vii).

The results from the rhizotron studies indicate that Maseno EH14 exhibits a post-attachment *Striga* resistance mechanism which is comparable to the observations of Mutinda *et al*., 2018 with KSTP 94 maize variety. The few parasite seedlings indicate that the parasite is not able to effectively breach the host cell layers namely the epidermis, cortex, pericycle and endodermis to enable it form vascular connections to extract water and nutrients from the host. Small (short) parasite seedlings observed on Maseno EH14 (Fig. 6) indicate that even after successful penetration, the parasite is unable to effectively extract nutrients from the resistant host. This was further elucidated by histological analysis of the *Striga*-host interactions at the point of attachment at 9 days after infection to show the cells at the host-parasite interphase as indicated in Fig. 8. The results show that *Striga* was unable to effectively colonize the Maseno EH14 hybrid maize. Close-up microscopic images reveal that although the parasite had successfully attached on the host root, further advancement and penetration into the host was blocked (Figure 8Ai). A histological analysis of the transverse section at the parasite-host junction showed that parasite penetration was blocked at the endodermis. Rather than penetrate the cortex to make vascular connections with the host, the parasite infectious organ circled the endodermis and exited (Figure 8Aii). This resistance mechanism was observed in seven out of 10 sections made. A similar observation was made in Maseno EH11 (Figure 8Bi and Bii), albeit less frequently (2 out of 10). But in contrast, in PHB3253, *Striga* successfully invaded the host roots. A close-up image of *Striga* infecting PHB3253 show a well-developed haustorium that has advanced to reach the host's stele where xylem vessels are located. The parasite is also well developed and vegetative – a sign of good nourishment from the host (Figure 8Ci). A closer look at the parasite-host junction histologically reveals that the parasite in most cases, successfully penetrated the host cortex into the endodermis to form parasite-host xylem to xylem connections resulting into a successful parasite-host attachment (Figure 8Cii)

These results are in agreement with Mutinda *et al*. 2018 where *Striga* seedlings only managed to penetrate the host's tissues of an open pollinated maize variety KSTP 94 up to the cortex and did not go beyond the endodermis thereby failing to establish parasite-host xylem to xylem connections. Several possibilities can be advanced to explain this inability of the parasite to

effectively infect the host as described by Yoshida *et al*., 2009 where three layers of host resistance occurring at the epidermis, cortex and endodermis are documented. The mechanism is attributed to cell wall thickening including lignification, secondary metabolites and programmed cell death at the interphase of the host and parasite. Amusan *et al*. 2008 also attributes the failure by the haustorium to penetrate the endodermis layer to other physiological and/or biochemical defense responses and a tough mechanical sclerenchyma tissue which might have acted as a barrier to haustorial penetration as observed in a maize inbred line ZD05. In many cases, this is the action of reinforcement of the cell wall by various processes such as carbohydrates, callose, xylan and secondary metabolites such as lignin. These results affirm the finding that Maseno EH14 exhibits some kind of resistance response against *Striga* parasitism. This is reminiscent of cell wall fortification as the most dominant mode of action for stopping invasion of the parasite as described by Mallu *et al*. 2021. The same can be said about Maseno EH11, although such response is weaker compared to Maseno EH14.

Conclusion

This study has shown that Maseno EH14 hybrid maize variety exhibits *Striga* tolerance which is attributable to post-attachment *Striga* limitation on haustorium growth and establishment. The mechanism could be linked to mechanical and/or chemical processes in the cortex thus becoming a good source of genetic material for the development of sustainable management of *Striga* and could provide genes leading to development of maize varieties with host-based resistance.

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Tables and Figures

Table i: Mean Squares of Striga Emergence and Counts for the Maize Varieties

Source of Variation	Df	DTSE	C8WAE	C10WAE	C12WAE	CUMC
Location	1	5626.02***	2532.66***	6980.05***	9155.06***	52696.36***
Season	1	212.82	16.54	112.53	191.35	812.54
Replication	2	94.62	39.17	145.34	207.27*	999.22*
Variety	4	453.78**	400.99***	1321.06***	1833.39***	9812.08***
Location x Variety	4	123.23	315.32***	912.12***	1070.19***	6482.64***
Season x Variety	4	335.19*	15.87	45.1	30.17	235.51
Location x Season	1	170.02	31.08	130.45	215.95	1004.5
Location x Season x Variety	4	68.14	18.19	50.36	32.73	274.97

*P≤0.05, **P≤0.01, ***P≤0.001, Df-Degree of freedom, DTSE-Days to *Striga* Emergence from crop emergence, C8WAE-*Striga* count at 8 Weeks after Crop Emergence (WAE), C10WAE-*Striga* count at 10 WAE, C12WAE-*Striga* count at 12 WAE and CUMC-Cumulative *Striga* Count

Table ii: Effect of Maize varieties on the Days to *Striga* Emergence

Maize Variety	Mean Days to *Striga* Emergence
EH14	61.3a
EH11	56.8ab
H516	50.2bc
H513	47.9bc
PHB3253	47.0c
Mean	52.62
C.V (%)	21.37
$LSD_{0.05}$	9.29

Means followed by the same letter are not significantly different using Fisher's Least Significant Difference (LSD) test at P<0.05, C.V-Coefficient of Variation

Table iii: Mean *Striga* counts for the Maize varieties in the *Striga* infested locations across the seasons

Variety	8 WAE	10 WAE	12 WAE	Cumulative Count
	Plants ($Log_{10}X+001$)			
PHB3253	12.78(2.04)a	24.45(2.72)a	29.67(3.03)a	66.89(3.71)a
H513	11.11(1.89)a	17.96(2.5)b	22.15(2.71)b	51.22(3.43)b
H516	10.44(1.77)a	19.24(2.29)ab	22.72(2.60)b	52.40(3.23)b
EH11	1.64(0.71)b	2.71(1.03)c	3.40(1.20)c	7.75(1.68)c
EH14	0.43(0.27)b	1.17(0.65)c	2.48(1.04)c	4.08(1.33)c
Mean	7.28(1.34)	13.1(1.84)	16.09(2.12)	36.47(2.68)
C.V (%)	59.54(21.35)	52.84(18.68)	44.37(16.36)	46.85(15.76)
$LSD_{0.05}$	3.58(0.24)	5.72(0.28)	5.89(0.29)	14.12(0.35)

Means followed by the same letter in a column are not significantly different using Fisher's Least Significant Difference (LSD) test at P<0.05, C.V-Coefficient of Variation, WAE-Weeks after crop Emergence

Table iv: Mean Squares of plant growth aspects for the maize varieties evaluated under natural *Striga* infestation

Source of Variation	Df	DTF	PHT	YIELD	SEEDWT
Location	3	295.54***	51950.01***	24.13***	417.38***
Season	1	9.34	7191.34***	2.51	1695.46***
Replication	2	1.91	271.56	2.63	34.91*
Variety	4	65.07***	1671.68*	0.73	40.70**
Location x Variety	8	17.53***	263.98	1.57	10.17
Season x Variety	4	3.09	414.52	1.59	9.53
Location x Season	2	86.54***	303.62	24.95**	169.03**
Location x Season x Variety	8	4.91	699.98	1.66	8.47

*P≤0.05, **P≤0.01, ***P≤0.001, Df-Degree of freedom, DTF-Days to tasseling, PHT-Plant height, YIELD - Grain yield in t ha^{-1} and SEEDWT-100 Seed weight

Table v: Effect of Location on Days to tasseling, plant height, yield and 100 seed weight

Location	Days to Tasseling	Plant height (cm)	Yield (t/ha)	100 Seed weight (g)
Maseno	66.7a	219.73a	3.72a	24.47b
Nyahera	62.3b	150.97b	2.00b	19.37c
Kibos	60.6c	225.95a	3.31a	26.62a
Mean	63.2	198.88	3.01	23.49
C.V (%)	3.1	11.8	35.2	14.3
$LSD_{0.05}$	1.02	12.15	0.55	1.73

Means followed by the same letter in a column are not significantly different using Fisher's Least Significant Difference (LSD) test at P<0.05, C.V-Coefficient of Variation

Table vi:Effect of maize varieties on Days to tasseling, plant height and 100 seed weight across the three locations

Variety	Days to Tasseling	Plant height (cm)	100 Seed weight (g)
EH14	65.8a	207.56a	24.81a
EH11	64.2b	207.89a	24.29ab
PHB3253	62.9bc	185.17b	21.39c
H516	61.9cd	200.0ab	22.42bc
H513	61d	193.81ab	24.53ab
Mean	63.2	198.88	23.49
C.V (%)	3.1	11.8	14.3
$LSD_{0.05}$	1.3	15.69	1.42

Means followed by the same letter in the column are not significantly different using Fisher's Least Significant Difference (LSD) test at P<0.05, C.V-Coefficient of Variation

Table vii: Pearson Correlation coefficients for the Striga and Crop Parameters of the Maize Varieties

Parameters	PHT	DTSE	C8WAE	C10WAE	C12WAE	CUMC	YIELD	SEEDWT
DTF	-0.2287	0.095	-0.1119	-0.1023	-0.0981	-0.1031	-0.0677	-0.1825
PHT		0.9334***	-0.778**	-0.7782**	-0.781**	-0.781**	0.8612**	0.9533**
DTSE			-0.8371**	-0.8395**	-0.8427**	-0.8429**	0.8422**	0.8793**
C8WAE				0.9934***	0.9937***	0.996***	-0.7501**	-0.7309*
C10WAE					0.9987***	0.9993***	-0.7584**	-0.7479**
C12WAE						0.9995***	-0.7444**	-0.7478**
CUMC							-0.7526**	-0.7466**
YIELD								0.8941***

*P≤0.05, **P≤0.01, ***P≤0.001, DTF-Days to tasseling, PHT-Plant height, DTSE-Days to *Striga* Emergence from crop emergence, C8WAE-*Striga* count at 8 Weeks after Crop Emergence (WAE), C10WAE-*Striga* count at 10 WAE, C12WAE-*Striga* count at 12 WAE and CUMC-Cumulative *Striga* Count, YIELD-Total Grain Weight and SEEDWT- 100 Seed Weight

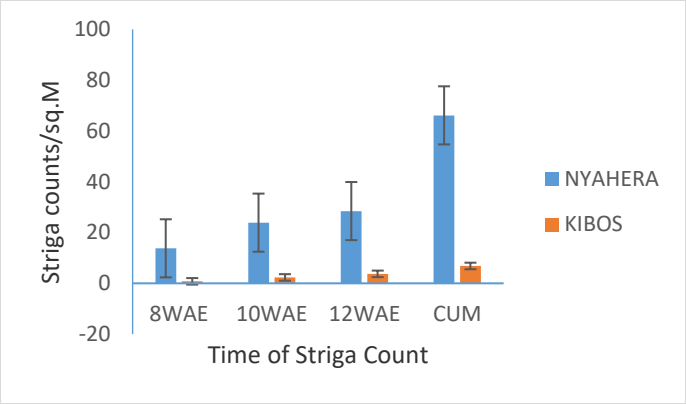


Fig. 1: *Striga* incidence for the Locations across the seasons

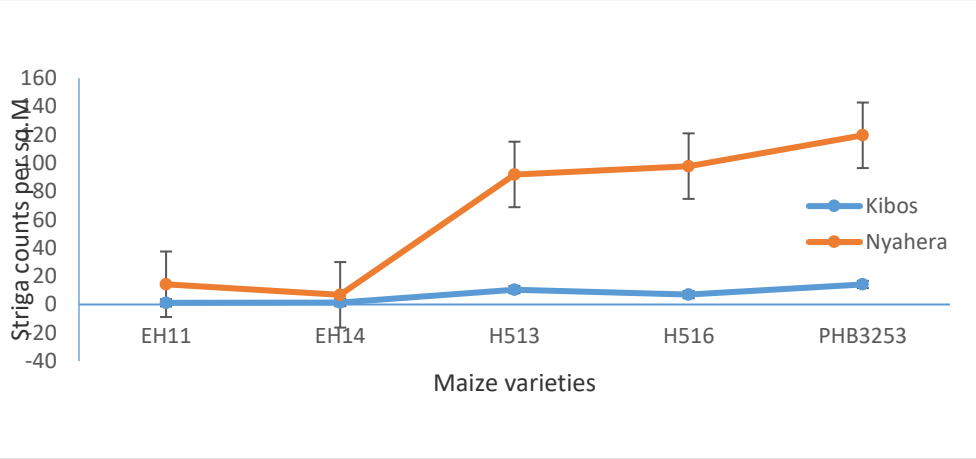


Fig. 2: The influence of location by variety interaction on cumulative *Striga* count in Kibos and Nyahera

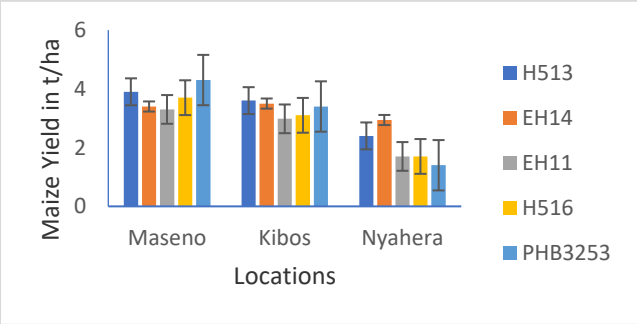


Fig 3: Average maize yield per Location

Fig. 4: *Striga hermonthica* seedlings growing on the roots of maize varieties screened on rhizotrons 21 days after infection with pre-germinated *Striga hermonthica* seeds. Plate A is Maseno EH14 characterized by fewer and smaller attachments; B and C are EH11 and PHB3253 respectively with relatively many attachments of *Striga* seedlings

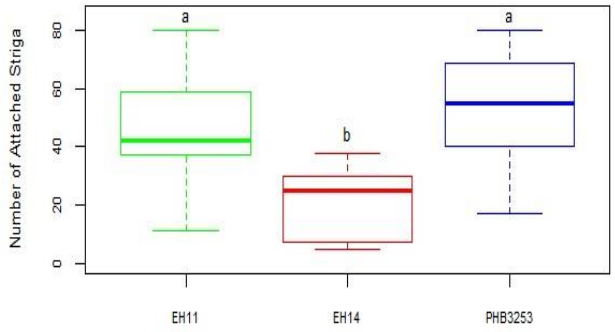


Fig. 5 Number of *Striga* attachments on roots of EH11, EH14 and PHB3253 maize varieties. Box plots with same letters are not statistically different (P<0.05)

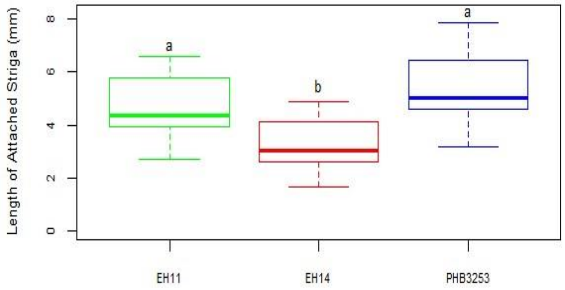


Fig. 6 *Striga* length (mm) on roots of EH11, EH14 and PHB3253 maize varieties. Box plots with same letters are not statistically different (P<0.05)

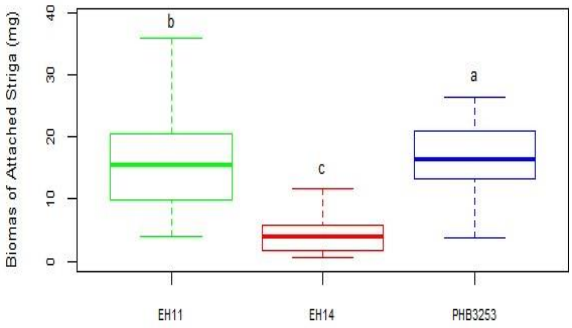
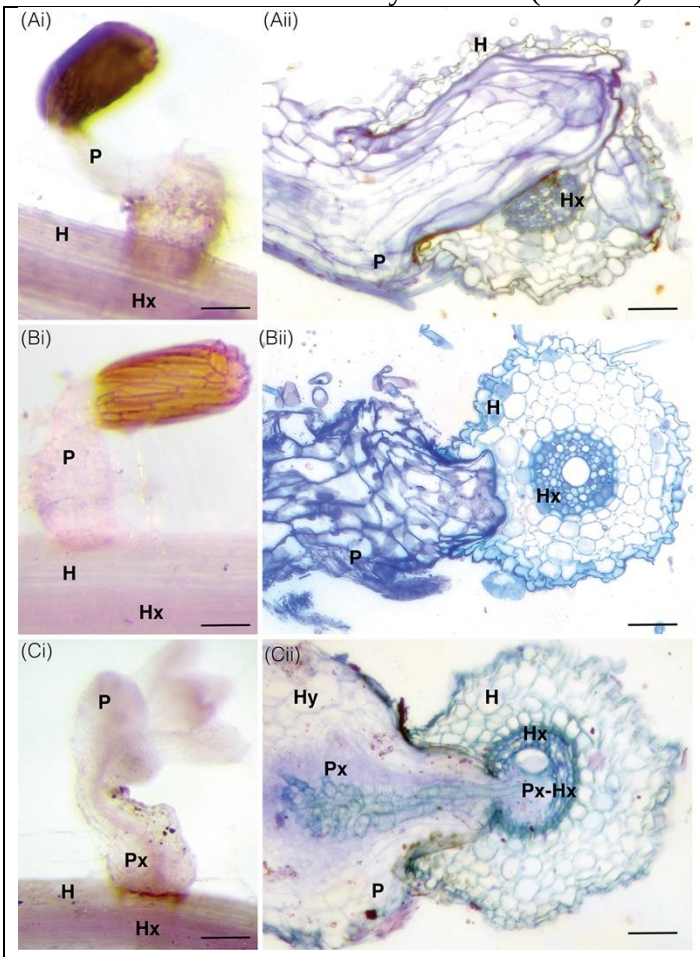


Fig. 7 *Striga* biomass (mg) on roots of EH11, EH14 and PHB3253 maize varieties. Box plots with same letters are not statistically different (P<0.05)



Mechanisms of *Striga* resistance in A: Maseno EH14. Ai is a close up of a *Striga* seedling infecting the host root. The attached seedling is small and poorly developed. Aii shows the transverse section of the same seedling infecting the host. Resistance mechanisms were able to push the infecting Striga away and impede it from making vascular connections. Bi is a close up of *Striga* infecting Maseno EH11. The parasite is also poorly developed. Bii shows a transverse section of the parasite invading the host. *Striga* was unable to enter the host and make vascular connections. Ci is the susceptible host PHB3253 showing a well developed haustoria and a clear vascular connection with the host. The parasite is also well developed and already vegetative. Cii shows the transverse section at the *Striga*-host interphase. *Striga* has already made a vascular connection with the host and the hyline body of the parasite is well developed suggesting efficient extraction of nutrients from the host.
H = Host; Hx = Host xylem; P = Parasite, Px = Parasite xylem; Px-Hx = successful parasite and host xylem connection; Hy = Hyline body. Scale bar Ai, Bi, and Ci = 1 cm; Scale bar Aii, Bii and Cii = 100 μm

Fig 8: Striga-host interactions at the point of attachment at 9 DAI

Antibacterial Potency of *Pelargonium Zonale* and *Psidium Guajava* Against Bacterial Wilt of Potato Under Greenhouse Condition

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Abstract

Pelargonium zonale and *Psidium guajava* plant extracts have demonstrated *in-vitro* antibacterial activity against *Ralstonia pseudosolanacearum* sp. nov. Nevertheless, their antibacterial effectiveness against this disease has not been examined under greenhouse condition. This study explored the antibacterial efficacy of ethanolic leave extracts of *P. zonale* and *P. guajava* in management of *R. pseudosolanacearum* sp. nov. of potatoes under greenhouse condition. The experiment was set in a completely randomized design (CRD) of 2*6 factorial arrangements [2 varieties (Shangi (Highly susceptible) and Sherekea (Moderately resistant) and 6 treatments] with 3 replicates. The treatments comprised; 2 ethanolic leave extracts (*P. guajava* and *P. zonale*) at 50 mg/mL, 2 positive controls [ENRICH BM (Bronopol 27%w/w) and KOBE 1.2 SL (Chrysophanol 12g/l)] at commercial rates and 2 negative controls (Untreated control and 1% DMSO). The soil media was inoculated with 10 mL of bacterial suspension adjusted to 600 nm OD (approximately 10^7 to 10^8 cfu/mL) per pot. Data was collected on disease incidence, disease severity, plant heights, number of stems, yield (Kgs) and number of bacterial wilt colony counts. The study results revealed that all the treated plants exhibited significantly low disease incidences, low area under disease progress curves (AUDPCs), high number of stems, high stem heights, low bacterial wilt colony counts and high yield (Kgs) compared to negative controls. Potato variety Sherekea exhibited the highest average efficacy from the two plant extracts; 0.14 for disease incidence, 1178.21 for AUDPC, 1.84 for stem height, 2.66 for bacterial wilt colony counts and 0.28 for yield (Kgs) respectively. These results demonstrated the synergistic effect of host plant resistance and/or tolerance and botanicals in management of *R. pseudosolanacearum* sp. nov. Further research is required to determine the effectiveness and stability of the two extracts against the target pathogen in the field to enhance their adoption and commercialization in the management of bacterial wilt pathogen in infested potato production fields.

Keywords: Antibacterial; *Pelargonium zonale*; *Psidium guajava*; *In-vivo*

1. Background

Potato (*Solanum tuberosum* L.) is ranked fourth after wheat, rice, and maize among the most important food crop globally, providing nourishment to over one billion people (Taiy *et al.*, 2017; Harahagazwe *et al.*, 2018; Gautam *et al.*, 2021). Regarding production volume, the crop is ranked second after maize in Kenya, contributing to food security and poverty alleviation. Its tubers are the major source of carbohydrates and other key dietary nutrients such as potassium, vitamin C, and fiber (Beals, 2019). Besides its nutritional values, the crop provides employment and income

generation for various stakeholders along its value chain (Taiy *et al.,* 2017; Mwakidoshi *et al.,* 2021). However, field infestation by bacterial wilt pathogens has affected its optimal production worldwide. Approximately 50 – 100% yield losses have been reported in bacterial wilt infested potato fields (Kromann *et al.,* 2014; Muthoni *et al.,* 2014).

Ralstonia pseudosolanacearum sp., a damaging pathogen found primarily in tropical, subtropical, and temperate climates, is the causal agent for potato bacterial wilt (Shimelis *et al.,* 2014; Boschi *et al.,* 2017). The pathogen is soil-borne, and overwinters in the soil, plant debris, and alternate hosts such as solanaceous weeds (Kromann *et al.,* 2014; Boschi *et al.,* 2017). Bacterial wilt pathogen is disseminated through latently infected tubers, infested water (irrigation water and or run-offs), infested soil adhering to tools, farm handlers' shoes, and through mechanical activities in the farm, which causes wounds to potato crop (Kwambai *et al.,* 2011; Shimelis *et al.,* 2014). Complete eradication of bacterial wilt pathogen has proved difficult due to a lack of satisfactory management options. Thus, farmers have been advised to adopt an ecofriendly management option [integrated disease management (IDM)] against the disease (Sharma *et al.,* 2017). Nevertheless, the site-specific nature and variety of bacterial wilt strains have constantly affected the effectiveness of IDM as a management option (Priou *et al.,* 1999; Karim & Hossain, 2018).

There is limited adoption of IDM in bacterial wilt management in potato fields which has resulted to widespread use of conventional bactericides (Sarkar & Chaudhuri, 2016; Biswal & Dhal, 2018). The overreliance on conventional bactericides as a management option against bacterial wilt has posed health risks to humans and the environment. When these bactericides leak into water bodies, they cause aquatic health problems whereas those that infiltrates into the soil cause terrestrial health hazards (Rahman *et al.,* 2012; Mulugeta *et al.,* 2020). Developing countries are the most affected since farmers in these countries lack quality personal protective equipment (PPEs) coupled with their sluggish adoption of good agricultural practices (GAPs) (Mulugeta *et al.,* 2020). The negative environmental impacts from the excessive use of conventional bactericides have consequently shifted various scientists' focus to research eco-friendly bacterial management options (Rahman *et al.,* 2012).

Studies by different researchers have confirmed various plant extracts' antibacterial activity against bacterial wilt pathogens (Abo-Elyousr *et al.,* 2009). Apart from commercialized botanicals (formulated plant extracts), plant extracts have shown efficacy against bacterial wilt pathogen when used in various forms; aqueous form, dried powder form, and or green manure form (Din *et al.,* 2016; Chen *et al.,* 2020; Abd-Elrahim *et al.,* 2021). The use of plant extracts in dried powder form and/or as green manure is advantageous since, in addition to their antibacterial activity, they also improve soil properties (biological, physical, and chemical properties) and plant growth parameters (Chen *et al.,* 2020). When used as dried powder (organic amendment), the powder mixes with soil water to release water-soluble secondary metabolites with antibacterial activity against bacterial wilt pathogen. The secondary metabolites' method of action against the bacterial wilt pathogen is compound/metabolite dependent (Din *et al.,* 2016).

Before moving on to in-vivo studies, the efficacy screening of plant extracts' antibacterial potency against plant pathogenic bacteria typically starts with in-vitro experiments to determine their viability (Abd-Elrahim *et al.,* 2021). The antibacterial activity of *P. zonale* and *P. guajava* against *Ralstonia pseudosolanacearum* sp. nov. was confirmed by in-vitro experiments by Okeyo *et al.,* (2022a). Therefore, the purpose of this study was to determine if *P. zonale* and *P. guajava* ethanolic

leave extracts were effective at controlling *R. pseudosolanacearum* sp. nov. of potatoes grown in a greenhouse.

2.0 Materials and methods

2.1 Bacterial isolation, identification, and inoculum preparation

Bacterial inoculum was isolated from infected potato plant tissues as described by Kelman (1954). Biovar identification of the isolated bacteria through the utilization of disaccharide sugars (lactose, maltose, and cellobiose) and oxidization of hexose alcohols (Mannitol, Sorbital, dulcitol, trehalose dextrose) was conducted according to Okeyo *et al.,* (2022a). The virulent colonies of the isolated bacteria were then multiplied in several plates containing Casamino Acid-Peptone-Glucose (CPG) medium at 28±10C for 48 hours. 48 hours old bacterial cells were harvested in sterilized distilled water, and the suspension was adjusted to attain the optical density (OD) of 600 nm (approximately 107 to 108 cfu / mL) using a spectrophotometer and hemocytometer, according to Mihovilovich *et al.* (2017) and Chen *et al.,* (2020).

2.2 Preparation of plant extracts

Leave samples from *Pelargonium zonale* and *Psidium guajava* were cleaned, dried, and crushed into fine powder and 1Kg of each powder was soaked in 10L of ethanol at a 1:10 (w/v) ratio for 48 hours with frequent stirring as described by Okeyo *et al.* (2022a). After 48 hours, the solutions were filtered to get rid of the solid particles using two layers of muslin cloths and Whatman filter papers. The filtrates were subsequently evaporated into pastes using a water bath at temperatures just below the boiling point of ethanol (60°C). The pastes were left to air dry overnight before being weighed and kept at 4°C.

2.3 Experimental design

A completely randomized design (CRD) of 2*6 factorial arrangement (two varieties and six treatments) with three replicates was used to set up the greenhouse experiment. The first level of treatments comprised two potato varieties (Shangi and Sherekea) which, according to Okeyo *et al.* (2023), were highly susceptible and moderately resistant, respectively. The second level of treatments consisted of ethanolic leave extracts (*Psidium guajava* and *Pelargonium zonale*) tested at a dosage rate of 50mg/mL, two commercial bactericides as positive controls [ENRICH BM (Bronopol 27%w/w), a conventional bactericide and KOBE 1.2 SL (Chrysophanol 12g/l) a botanical bactericide] applied at their commercial rates and two negative controls (1% DMSO as and untreated control).

2.4 Greenhouse experiment

The greenhouse experiment was carried out at the University of Nairobi field station, upper Kabete campus. Forest soil was collected from a tree forest (*Eucalyptus spp.),* which has been out of cultivation for over ten years, and autoclaved for 1 hour at 121°C as described by Mahmood *et al.* (2014). Upon cooling, 4 kg sterile plastic pots with a surface area of $0.03M^2$ were half-filled with the cooled sterile soil. Five pots were used per treatment translating to 60 pots per replicate. Uniform wounds/physical injuries were created on each well-sprouted certified seed potato tuber

using a sterile knife. The pots were inoculated with 10 mL of bacterial suspension adjusted to 600 nm OD (approximately 10^7 to 10^8 cfu / mL) using a syringe, as described by Mihovilovich *et al.* (2017). The injured tubers were planted at the centre of each half-filled plastic pot (one tuber per pot). The tubers were then covered with sterile soil to about ¾ full.

Each treatment (ethanolic leave extracts (*P. guajava* and *P. zonale*), ENRICH BM (Bronopol 27%w/w), KOBE 1.2 SL (Chrysophanol 12g/l), and 1% DMSO) was mixed with sterile distilled water in different containers at recommended rates and the mixed solutions applied as a soil drench to their target treatment pots at the rate of 90ml per pot translating to (3L/M2) as described by (Kumar, 2021). Two weeks after plant emergence, 2 foliar applications of the above treatments were applied on the emerged plants at 2 weeks intervals. Each treatment was mixed with sterile distilled water at recommended rates, and the solution was applied to respective test plants as a foliar spray using hand sprayers. Maximum plant coverage was observed during foliar treatment applications. All potato agronomic practices (watering, fertilization, insect pest, and disease control) except the application of additional bactericides were conducted according to potato optimal production requirements. The experiment was repeated once, and in each experimental period, the experiment was terminated once the test plants exhibited senescence symptoms.

2.5 Determination of *Ralstonia solanacearum* population in the soil at harvest

During the experiment termination phase, soil samples were taken from the rhizosphere of potato plants in respective treatments and shipped to the laboratory to assess *R. solanacearum* population. A sterile trowel was used to collect soil samples per pot from all five pots per treatment, and the samples were mixed thoroughly to form a composite sample from which 10 g of soil sample was sub-sampled and placed in plastic bags. The bags were labeled and sent to the lab for microbial scrutiny. Using Kelma's TZC agar media, bacterial isolation and quantification from soil samples were performed in the lab as described by Okeyo *et al.* (2023). The number of bacterial colonies was counted, and the bacterial population was determined using the following formula;

$$CFU/mL = \frac{Total\ number\ of\ colonies}{Plated\ volume\ (mL)} * dilution\ factor$$

2.6 Data collection

Data was collected on the number of stems, plant heights, disease incidence, disease severity, yield (Kgs), and bacterial colony counts. Disease indices (incidence and severity) data were recorded after plant emergence at two weeks intervals until the untreated control attained ≥80% wilt incidence (Mihovilovich *et al.,* 2017).

Disease severity scale of 1-3 based on the affected plant's degree of wilting, where 1 = healthy plant, 2 = ≤50% of the plant foliage wilted, and 3 = ≥50% of plant foliage wilted was used. The scored severity scales were converted to percent disease severity (%) using the following formula;

$$S = 100(\frac{\sum n}{N * Max.score\ in\ the\ scale})$$

Where S = percent disease severity, Σn = summation of wilt scores, and N = an overall number of plants evaluated per treatment (Mihovilovich *et al.,* 2017).

Disease incidence was recorded by assessing the number of symptomatic plants per treatment at two weeks intervals. The scored values were converted to percent bacterial wilt incidence [BWI (%)] using the following formula;

$$BWI(\%) = \frac{\mathrm{X}}{\mathrm{Y}} * 100$$

Where BWI = percent bacterial wilt incidence, X = the number of symptomatic plants, and Y = the overall number of assessed plants per treatment (Okeyo *et al.,* 2018).

The harvested tubers were graded as symptomatic tubers (either externally visible and/or internal bacterial wilt symptoms) and asymptomatic tuber (for tubers without external and internal bacterial wilt symptoms). The harvested tubers were weighed and weights recorded in kilograms (Kgs).

2.7 Data analysis

The data from the two experiments, except disease severity, was first subjected to Levene tests to test for equal variance (Levene, 1960) before testing for mean differences using the Mann-Whitney U test at a 5% probability level (Wilcoxon, 1945; Mann & Whitney, 1947). Since there were no significant differences between the treatments, the data were subsequently pooled together and then subjected to normality testing using Shapiro-Wilk tests (Shapiro & Wilk, 1965). Where the data lacked equal variance as well as a normal distribution, the data were transformed using the formula;

$$\mathrm{Log}\,(X + 1)$$

The pooled data were then subjected to a two-way analysis of variance (ANOVA) using R software, version 4.2.2 (R Studio Team 2020). Tukey's Honest significant difference (HSD) at $p \leq 0.05$ in agricolae package was used to separate the treatment means.
The percent disease severity data per treatment was used to compute the area under disease progress curves (AUDPCs) using the following formula;

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2}\right)(t_{i+1} - t_i)$$

Where yi= percent severity score at the ith observation, ti = time in days at the ith observation, and n= the total number of observations.

3.0 Results

3.1 Biovar identification through carbohydrate fermentation tests

All of the disaccharide sugars (lactose, maltose, and cellobiose) and hexose alcohols (mannitol, sorbitol, dulcitol, trehalose, and dextrose) were oxidized by the bacterial isolate within five days of incubation. The universal bottles that had been inoculated with the isolated bacteria changed colour from red to yellow to show the oxidation reaction, whilst the untreated controls (non-inoculated bottles) retained the red colour.

3.2 Efficacy of ethanolic leave extracts of *P. zonale* and *P. guajava* against *Ralstonia pseudosolanacearum* sp. nov. of potatoes under greenhouse condition

The analysis of variance (ANOVA) results revealed highly significant interactions between treatments and varieties (Treatment x variety) among all the tested parameters except for the number of stems (NS), stem heights (SH), and Final wilt incidence (FWI) (Table 1.0). ANOVA results also revealed highly significant effects among treatments and varieties across all the response values.

Table 1.0: F-test statistics of two-way ANOVA of percent plant emergence, number of stems, stem heights, colony counts, final wilt incidence, number of asymptomatic tubers and weight (Kgs)

Source of variation	Df	NS	SH	CC	FWI	NAT	Weight (Kgs)
Treatment	5	5.61***	3.95**	10447.81***	4.77***	155.88***	66.20***
Variety	1	42.20***	50.48***	2773.66***	140.48***	962.17***	469.04***
Treatment * variety	5	0.63	2.02	10.50***	1.63	49.67***	12.46***
Residuals	60						

Significance codes: 0 '***', 0.001 '**', 0.01 '*' 0.05 's' 0.1 '' 1. Df = Degree of freedom, NS= Number of stems, SH = Stem heights, CC = colony counts, FWI = Final wilt incidence and NAT = Number of asymptomatic tubers.

3.3 Effect of ethanolic leave extracts of *P. zonale* and *P. guajava* treatment application on mean number of stems and stem heights

The mean number of stems significantly differed at $p \leq 0.05$ across treatments and varieties. However, the interaction effect was insignificant at $p \leq 0.05$ among treatments and varieties (Treatment x variety) (Table 1.0). KOBE 1.2 SL recorded the highest number of stems in Shangi (0.93) and Sherekea (0.88), untreated controls, and 1% DMSO recorded the least for both varieties, respectively. Shangi had the highest overall mean number of stems (0.89), while Sherekea had the least (0.81). The transformed mean stem heights differed significantly at $p \leq 0.05$ across varieties. With the exception of the untreated control, all the transformed mean stem heights of Shangi were insignificantly different at $p \leq 0.05$ across all treatments. At the same time, those of Sherekea exhibited insignificant differences across all the treatments. Sherekea recorded the highest average mean stem heights, while Shangi recorded the least (Table 2.0).

Table 2.0: Effect off treatment application on transformed mean number of stems and stem heights for the two potato varieties

Treatments	Transformed mean number of stems and stem heights			
	Number of stems		Stem heights	
	Shangi	Sherekea	Shangi	Sherekea
Untreated control	0.86 ± 0.02 abcde	0.77 ± 0.04 e	1.69 ± 0.09 c	1.82 ± 0.03 a
Psidium guajava	0.91 ± 0.04 ab	0.80 ± 0.04 cde	1.78 ± 0.03 ab	1.85 ± 0.02 a
Pelargonium zonale	0.88 ± 0.03 abc	0.80 ± 0.07 cde	1.78 ± 0.04 ab	1.83 ± 0.03 a
ENRICH BM	0.87 ± 0.07 abcd	0.83 ± 0.07 bcde	1.78 ± 0.06 ab	1.83 ± 0.04 a
KOBE 1.2 SL	0.93 ± 0.05 a	0.88 ± 0.04 abc	1.78 ± 0.01 ab	1.83 ± 0.04 a
1% DMSO	0.86 ± 0.03 abcde	0.78 ± 0.03 de	1.72 ± 0.03 bc	1.81 ± 0.03 a
Grand mean	0.89	0.81	1.76	1.83
MSD	0.09	0.09	0.08	0.08

The values are average number of stems ± standard deviations. Means within the same column having same letter(s) do not differ significantly at $p \leq 0.05$, MSD = mean square displacement.

3.4 Effect of ethanolic leave extracts of *P. zonale* and *P. guajava* treatment application on potato bacterial wilt incidence and area under disease progress curve

Bacterial wilt incidences (BWIs) varied across treatments and varieties and were significantly different at $p \leq 0.05$ at 38 days after planting (DAP), 52 DAP, and 66 DAP. For Shangi, BWI commenced at 38 DAP and increased rapidly to 66 DAP. A part from *Pelargonium zonale* leaf extracts which exhibited BWI at 38 DAP, most treatments expressed BWIs at 52 DAP for Sherekea, and the BWI progressed slowly to 66 DAP (Table 3.0). In general, Shangi exhibited high final bacterial wilt incidences (FBWIs) at all treatment levels compared to Sherekea. The area under disease progress curves (AUDPCs) varied across treatments and varieties. For both varieties, untreated control and 1% DMSO recorded the highest AUDPCs of 2155.68 (untreated control) and 2154.28 (1% DMSO) for Shangi and 1236.55 (untreated control) and 1237.04 (1% DMSO) for Sherekea respectively. In general, Shangi exhibited high AUDPCs at all treatment levels compared to Sherekea (Figure 1.0).

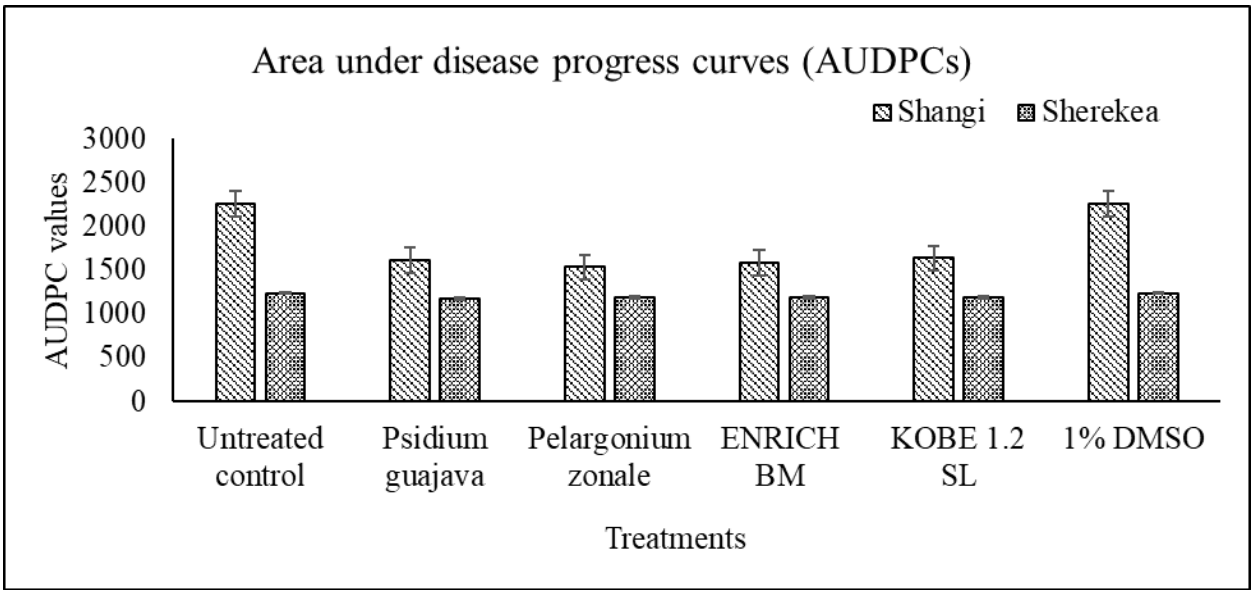

Figure 1. Effect off treatment application on Area under disease progress curve (AUDPC) of the Shangi and Sherekea potato varieties. Bars represent standard error.

Table 3.0: Effect off treatment application on mean bacterial wilt incidence for the two potato varieties

Treatments	38 DAP		52 DAP		66 DAP	
	Shangi	Sherekea	Shangi	Sherekea	Shangi	Sherekea
Untreated control	1.30 ± 0.65 a	0.00 ± 0.00 c	1.91 ± 0.00 ab	0.44 ± 0.68 cd	2.00 ± 0.00 a	0.93 ± 0.73 bcd
Psidium guajava	0.66 ± 0.72 abc	0.00 ± 0.00 c	1.23 ± 0.63 abc	0.00 ± 0.00 d	1.79 ± 0.12 ab	0.00 ± 0.00 e
Pelargonium zonale	0.71 ± 0.78 abc	0.22 ± 0.54 bc	1.52 ± 0.15 ab	0.22 ± 0.54 d	1.67 ± 0.09 ab	0.27 ± 0.66 de
ENRICH BM	0.71 ± 0.78 abc	0.00 ± 0.00 c	1.45 ± 0.20 ab	0.00 ± 0.00 d	1.67 ± 0.09 ab	0.49 ± 0.76 cde
KOBE 1.2 SL	0.54 ± 0.83 abc	0.00 ± 0.00 c	1.39 ± 0.72 ab	0.00 ± 0.00 d	1.74 ± 0.16 ab	0.44 ± 0.68 cde
1% DMSO	1.20 ± 0.60 ab	0.00 ± 0.00 c	1.92 ± 0.08 a	1.10 ± 0.54 bc	2.00 ± 0.00 a	1.20 ± 0.60 abc
Grand mean	0.85	0.04	1.57	0.29	1.57	0.56
MSD	1.06	1.06	0.81	0.81	0.88	0.88

The values are average bacterial wilt incidence ± standard deviations. Means within the same column having same letter(s) do not differ significantly at $p \leq 0.05$, MSD = Mean square displacement, DAP = Days after planting.

3.5 Effect of ethanolic leave extracts of *P. zonale* and *P. guajava* treatment application on potato yield parameters [number of asymptomatic tubers and tuber weights (Kgs)]

The mean number of asymptomatic tubers by visual assessment significantly differed at $p \leq 0.05$ across treatments and varieties. KOBE 1.2 SL (Chrysophanol 12g/l) of Sherekea recorded the highest number of asymptomatic tubers (1.87), while untreated control of Shangi recorded the least (1.41) (Table 4.0). Sherekea had the highest overall mean number of asymptomatic tubers (1.76), while Shangi had the least (1.59). However, dissection of all the sampled asymptomatic tubers per treatment per variety revealed brown discoloration of the vascular ring and the adjacent tissues extending to the pith and/or tuber cortex. Mean tuber wights (Kgs) differed significantly at $p \leq 0.05$ across treatments and varieties. KOBE 1.2 SL (Chrysophanol 12g/l) of Sherekea recorded the highest mean transformed tuber weights (0.31), while untreated control and 1% DMSO of Shangi recorded the least (0.17). Sherekea had the highest overall transformed mean tuber weights (0.29), while Shangi had the least (0.22).

Table 4.0: Effect off treatment application on transformed proportion/percent mean number of asymptomatic tubers and tuber weights (Kgs) for the two potato varieties

Treatments	Percent mean No. of asymptomatic tubers and tuber weights (Kgs)			
	Number of asymptomatic tubers		Tuber weighs (Kgs)	
	Shangi	Sherekea	Shangi	Sherekea
Untreated control	1.41 ± 0.04 g	1.71 ± 0.02 cd	0.17 ± 0.01 g	0.26 ± 0.02 def
Psidium guajava	1.68 ± 0.04 def	1.78 ± 0.01 b	0.24 ± 0.01 f	0.29 ± 0.01 abc
Pelargonium zonale	1.67 ± 0.03 def	1.75 ± 0.01 bc	0.25 ± 0.01 ef	0.28 ± 0.01 bcd
ENRICH BM	1.67 ± 0.01 ef	1.75 ± 0.01 bc	0.25 ± 0.01 ef	0.30 ± 0.02 ab
KOBE 1.2 SL	1.65 ± 0.03 f	1.87 ± 0.02 a	0.25 ± 0.01 ef	0.31 ± 0.01 a
1% DMSO	1.43 ± 0.02 g	1.70 ± 0.02 de	0.17 ± 0.01 g	0.27 ± 0.01 cde
Grand mean	1.59	1.76	0.22	0.29
MSD	0.05	0.05	0.02	0.02

The values are average proportion of symptomatic tubers ± standard deviations. Means within the same column having same letter(s) do not differ significantly at $p \leq 0.05$, MSD = mean square displacement.

3.6 Effect of ethanolic leave extracts of *P. zonale* and *P. guajava* treatment application against *Ralstonia pseudosolanacearum sp. nov.* colony counts

The transformed mean bacterial wilt colony counts from soils sampled around the rhizosphere of the two potato varieties differed significantly at $p \leq 0.05$ across treatments and varieties. Untreated control and 1% DMSO recorded the highest mean transformed colony counts of 3.15 and 3.16 for Shangi and 3.06 and 3.05 for Sherekea, respectively. *Pelargonium zonale* recorded the least mean transformed colony counts of 2.70 for Shangi and 2.63 for Sherekea (Table 5.0).

Table 5.0: Transformed mean bacterial wilt colony counts per treatment recorded from the soil samples sampled around the rhizosphere of two potato varieties

Treatments	Transformed mean bacterial wilt colony counts	
	Shangi	Sherekea
Untreated control	3.15 ± 0.01 a	3.06 ± 0.00 b
Psidium guajava	2.78 ± 0.01 d	2.69 ± 0.00 f
Pelargonium zonale	2.70 ± 0.00 f	2.63 ± 0.01 g
ENRICH BM	2.80 ± 0.01 c	2.73 ± 0.00 e
KOBE 1.2 SL	2.78 ± 0.01 d	2.70 ± 0.01 f
1% DMSO	3.16 ± 0.00 a	3.05 ± 0.00 b
Grand mean	2.9	2.81
MSD	0.01	0.01

The values are average transformed mean bacterial wilt colony counts ± standard deviations. Means within the same column having same letter(s) do not differ significantly at $p \leq 0.05$, MSD = mean square displacement.

4.0 Discussion

The bacterial isolate completely oxidized all of the disaccharide sugars and hexose alcohols within 5 days of incubation. These results confirmed the findings of Rahman *et al.,* (2010), Popoola *et al.,* (2015), Boschi *et al.,* (2017), Khasabulli *et al.,* (2017), and Okeyo *et al.,* (2022a) who classified *Ralstonia pseudosolanacearum* sp. nov. bacterial isolate with similar traits as biovar III race 1 *(Ralstonia solanacearum* (phylotype I)). The mean number of stems varied across treatments and varieties. All the treated pots exhibited a higher mean number of stems per variety than untreated controls. The soil drench of various treatments (plant extracts and conventional bactericide) used in this study might have suppressed apical dominance on the planted tubers resulting in an increased number of lateral buds, sprouts and hence increased number of stems (Biruk-Masrie *et al.,* 2015). Similarly, Biruk-Masrie *et al.,* (2015) also reported many stems from potato tubers treated with extracts from essential oils. KOBE 1.2 SL (Chrysophanol 12g/l), recorded the highest mean number of stems for both varieties, and this could be an indication that KOBE 1.2 SL had high phytochemical composition compared to other treatments. In general, Shangi recorded the highest number of stems per treatment compared to Sherekea, which can be attributed to differences in their genetic traits and a high number of tuber eyes recorded on the Shangi variety (Nielson *et al.,* 1989).

The average stem heights varied significantly between varieties at $p \leq 0.05$. In contrast to Sherekea, the mean stem heights of Shangi did not differ significantly across any of the treatments except for untreated control. Both varieties did not exhibit significantly different stem heights from pots with various treatment applications compared to negative control pots. The high stem heights from treated pots can be attributed to low disease indices scored (Priou *et al.,* 1999; Chen *et al.,* 2020). Additionally, studies by Okeyo *et al.,* (2022b) reported the presence of Succinic acid (one of the major components used in the manufacture of bio-stimulants) in low concentrations from the ethanolic leave extracts of *Psidium guajava* and *Pelargonium zonale,* and this could have resulted to slight increase in stem heights in plants treated with the two extracts compared to untreated plants (Zeikus *et al.,* 1999; Levchyk *et al.,* 2017). Liu *et al.,* (2016) also reported the bio-stimulant effect of Chrysophanol

on potato plants, which can explain the high stem height in the plants treated with Chrysophanol. Sherekea exhibited the highest average stem heights compared to Shangi, and this can be attributed to the difference in the expression of genetic traits for plant height from the two varieties.

The final bacterial wilt incidences (FBWIs) and area under disease progress curves (AUDPCs) varied across treatments and varieties. All the treated plants recorded low FBWIs and AUDPCs compared to negative controls. This was consistent with the study's findings of Oboo *et al.* (2014), Chen *et al.* (2020), and Abd-Elrahim *et al.* (2021), who reported in-vivo efficacy of plant extracts (essential oils) against bacterial wilt of potatoes with regards to disease incidence. It has been demonstrated that the bacterial wilt pathogen can be controlled by induced host plant resistance through the use of KOBE 1.2 SL (Chrysophanol 12g/l) and ENRICH BM (Bronopol 27%w/w) (https://agroduka.com/enrich-bm; Liu *et al.*, 2016), while the mode of action of both *P. guajava* and *P. zonale* against this pathogen is still unknown. In general, Shangi exhibited high FBWIs and AUDPCs at all treatment levels compared to Sherekea, and this can be attributed to varied degrees of resistance levels of the two varieties to bacterial wilt pathogen (Patil *et al.*, 2012; Muthoni *et al.*, 2014; Okeyo *et al.*, 2023).

The average proportion of asymptomatic tubers and tuber weight (kgs) significantly differed across treatments and varieties. All the treated plants recorded a significantly higher number of asymptomatic tubers and tuber weights (Kgs) than negative controls. These results concurred with that of Abd-Elrahim *et al.*, (2021), who revealed increased yield parameters from bacterial wilt-inoculated potato plants treated with plant extracts in-vivo. Sherekea variety recorded the highest yield parameters per treatment compared to Shangi, and this can be attributed high bacterial wilt resistance level of Sherekea compared to Shangi (Okeyo *et al.,* 2023). KOBE 1.2 SL (Chrysophanol 12g/l) recorded the highest yield parameters per variety, which can be attributed to its high concentration of antibacterial compound compared to other treatments. The overall proportion of antibacterial compounds per plant extract was less than 10% for both *P. zonale* and *P. guajava* (Okeyo *et al.,* 2022b). Most of the harvested tubers lacked externally visible symptoms, which can be attributed to late bacterial symptom establishment and certified tubers used in this study. However, dissection of all the sampled asymptomatic tubers per treatment revealed 100% bacterial wilt incidence (brown discoloration of the vascular ring and adjacent tissues extending to the pith and/or tuber cortex). The 100% wilt incidence on dissected tubers indicates that potato tubers harvested from all the treated pots had latent infection symptoms and, therefore, cannot be used as seeds (Patil *et al.*, 2012). A hundred percent wilt incidence on the sampled tubers can be attributed to wounds created on the tubers at planting to avoid disease escape.

Bacterial wilt colony counts from soil samples around the rhizosphere revealed significantly low bacterial wilt populations from all treated pots compared to the negative controls. These results confirmed the study outcomes of Chen *et al.* (2020) and Abd-Elrahim *et al.* (2021), who reported a reduced bacterial wilts population from soils sampled from pots treated with various plant extracts in-vivo. *P. zonale* recorded the least mean bacterial wilt population among all the treated pots for both varieties (Shangi and Sherekea). These results confirmed the in-vitro study results of Okeyo *et al.* (2022a), who reported *P. zonale* as the most effective plant extract against bacterial wilt of potatoes. In general, Shangi had the highest bacterial wilt population per treatment, which can be attributed to the high disease indices scored per treatment for Shangi compared to Sherekea.

5.0 Conclusion

The present study revealed in-vivo antibacterial efficacy of *P. zonzle* and *P. guajava* leave extracts against soil inoculated *R. pseudosolanacearum* sp. nov. However, the efficacy results were dependent on resistant levels of varieties used in the study. Sherekea (moderately resistant variety) demonstrated the highest efficacy of the two plant extracts, illustrating the synergistic effect of host plant tolerance/resistance and botanicals in the management of bacterial wilt of potatoes. These results were comparable to those of Enrich BM (Bronopol 27%w/w) a conventional bactericide and KOBE SL (Chrysophanol 12g/l) a botanical bactericide. Additional research should be conducted to determine the effectiveness and stability of *P. zonale* and *P. guajava* against the target pathogen under field condition.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Influence of a Shared Learning Platform on Participation in Seed Potato Multiplication among Small Scale Farmers in Kamara Ward

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Abstract

Food security remains a challenge in Sub Saharan Africa and has been attributed to several factors among them, low productivity of agricultural resources. Investment in agricultural research and technology are required to bring about change in food security. Innovation platforms have been used as vehicles in agricultural research for development. Potato (solanum tuberosum) is a staple food second after maize in Nakuru County. Although potato is predominantly grown by small scale farmers, they have limited access to quality seed potato. They are not participating in seed potato multiplication due to limited knowledge and skills and their farms are below the minimum requirement of 5 acres by KEPHIS. The research was designed as a descriptive survey using participatory action research methodologies in which baseline data was collected and analyzed then an intervention done. An end line survey was done data collected and analyzed again. The target population consisted of all small - scale potato farmers and all key informants in the seed potato value chain in Nakuru County The accessible population was potato small scale farmers from Kamara Ward Kuresoi North Sub County Kenya. The Key Informants (KI)were from Kuresoi North and Molo Sub Counties of Kenya. Purposive sampling was used to select 120 small scale potato farmers from Kamara Ward, 10 key informants for the baseline survey. Forty small scale farmers were purposively selected from those who participated in the baseline survey for the action plan (SLP). Data was collected on the farmer's knowledge and skills on seed potato multiplication before, during and after the intervention. Statistics Data Analysis (STATA) version 13 was used to analyze descriptive data. Thematic content analysis was used to analyze themes from FGDs, T-test, Chi square, ANOVA analysis and a regression were run to test the relationship between the outcomes and the intervention. From the baseline it was found that that SSFs experience complex problems that required all stakeholders in SPM and that the solution was the SLP. The SSFs who participated in the SLP gained from group formation and 10 SSFs each 1acre for seed potato multiplication. This acreage enabled them to participate in SPM as they donated more than 10 acres. There was increased knowledge and skills gained in SPM from the SLP which led to increased seed potato, increased participation, Establishing networks in the SLP. ADC Molo agreed to provide farm inputs and market for seed potatoes for the SSFs. This could enhance increased availability and accessibility of seed potato and increased incomes. This could also enhance dissemination of knowledge and skills on seed potato multiplication among SSFs and use of shared learning platform by small scale seed potato farmers.

Key Words; Shared learning platform, Innovation, Kowledge, small scale farmers

1.0 Introduction

Food security remains a challenge in Sub Saharan Africa (SSA). This has been attributed to several factors among them high population growth rate and low productivity of agricultural resources (Ogundari & Bolarinwa, 2018.). Majority of the SSA population depend directly or indirectly on the agricultural sector for their livelihoods (Muyanga & Jayne, 2019; Waaswa & Satognon, 2020). Potato is grown in many Sub-Saharan countries mainly by small scale farmers as a staple food and for commercial purposes (Chindi *et al*, 2017). However, potato production in these countries remains low. One of the major factors contributing to low potato production is use of low- quality seed potato, especially by small scale farmers (Food and Agriculture Organization [FAO],2018). Many SSFs lack access to quality seed potato due to limited availability coupled with high cost. In addition, many have limited knowledge and skills on seed potato multiplication (Tadesse *et al*, 2020). Agricultural research is a major source of knowledge and skills on agricultural technologies. In recent years, agricultural research has shifted from conventional practice towards more collaboration between researchers and other stakeholders, by using models such as the Innovation platform (IP) (Chilundo *et al*., 2020). A Shared Learning Platform (SLP) is an innovation platform that allows for a process of working as a team to achieve a common objective. (Memari, 2019). The SLP is defined as a place for learning and for change, the stake holders share knowledge and learn together for positive change (Chilundo *et al.,* 2020). The SLP has been used to bring together team members to share knowledge and complement each other's skills, as they tend to obtain better results and achieve goals faster (Memari,2019). The SLP comprises of a group of individuals who often represent organizations with different backgrounds and interests. They could be farmers, traders, food processors, researchers, government officials (Chilundo et al., 2020). The members come together to diagnose problems, identify opportunities and find ways to achieve their goals (Soeparno, Perbangsa & Pardamean, 2018). They may design and implement activities as a platform, or coordinate activities by individual members (Chilundo et al. 2020).

In the shared learning platform people work as co-researchers with experts to generate evidence of practical relevance on implementation processes with and for people (D'Ambruoso, 2019). The SLP is an innovation that is social in nature with supporting connections between learners and the customization of content based on their needs (Soeparno *et al*.,2018) There is total interaction of actors and the science suppliers as knowledge is shared among participants (Osumba & Reche 2020). Learning occurs through a mix of formal, informal and experiential learning. The focus is structured on and around the process of discovering optimal solution as they share thoughts for innovations (Boileau, 2017). The learners give feedback and post queries which results in healthy discussions (Memari, 2019). A SLP is time saving, offers opportunities for collaborations, increases teaching productivity and engages learners through increased involvement (D'Ambruoso, 2019). The SLP has been used by farmers to improve agricultural productivity, a good example being farmer field school (FFS) which have been used globally (Wang, Wang, Liu & Wu 2020). The FFS is a group-based learning process that brings together concepts and methods. (Osumba & Reche 2020). Innovation Platforms (IPs) have been used in the value chain as vehicles in agricultural research and development for shared learning among actors (Soeparno,*et al*, 2018). A value chain (VC) can be defined as a business model that describes the full range of activities needed to create a product or service (Jahan, 2017). SLPs has been used as an innovation by researchers for the development of shared learning among the actors in the value chain. The VC comprises of many actors with each having a role to play in specific activity. Shared learning platform as an innovation would increase the probability of successful interventions in the small- scale farmers seed potato system (CIP, 2019). There are two

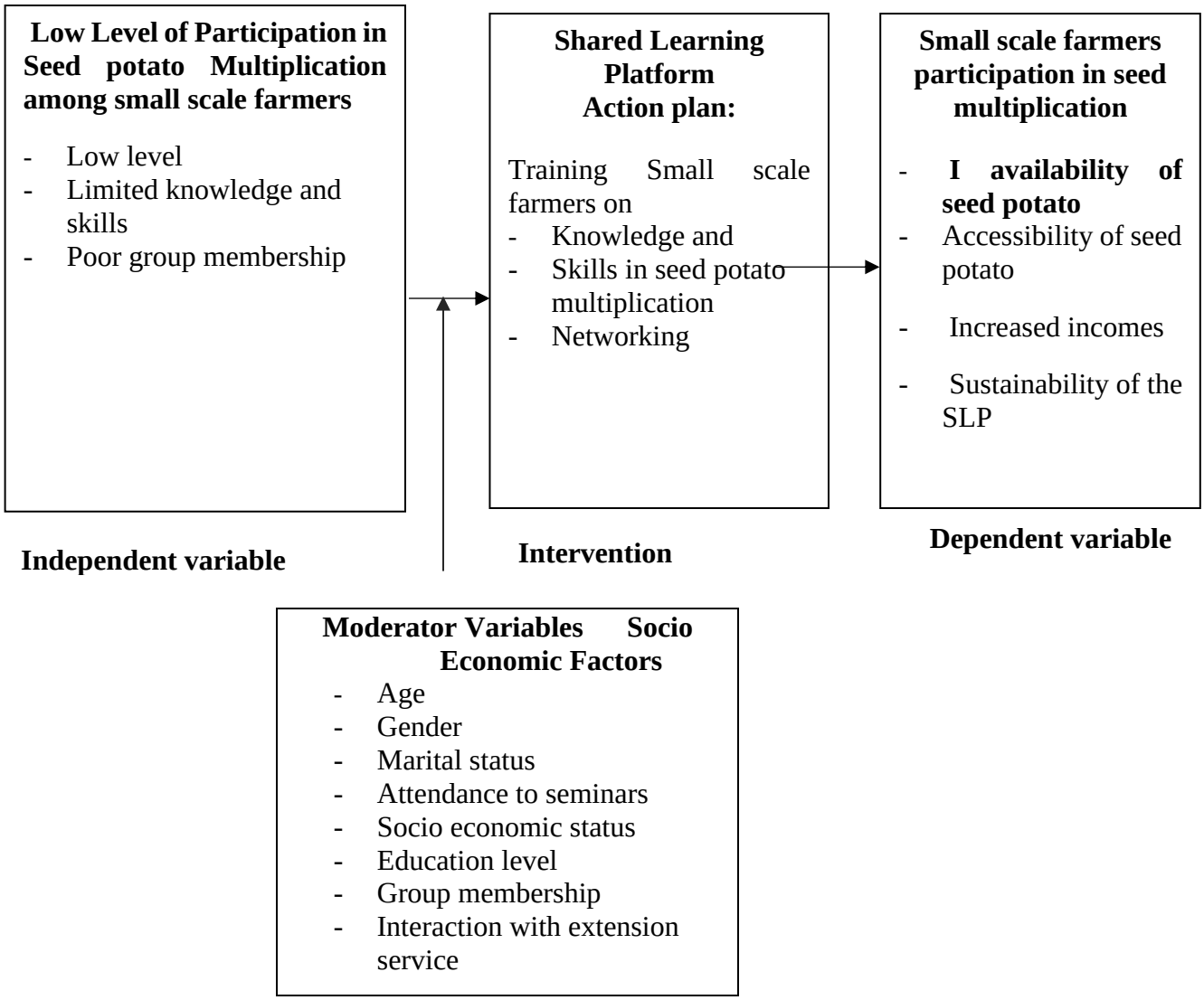
types of seed potato systems practiced by farmers; informal and formal. In the informal seed system, farmers use the remains from ware potato that is used for food and commercial purposes. The formal system is where seed is produced from mother plant through several stages to certified seed referred to as seed potato value chain. The seed potato value chain (SPVC) comprises of many actors each having a specific role in seed production stage (Tadesse et al., 2020). The SPVC begins with the mother from which the mini tubers are obtained to the Early Generation seed (EGS) is a stage of seed multiplication which is a planting material commonly referred to as seed ((Alliance for a Green Revolution in Africa [AGRA], 2018). This can be achieved by the trainings targeted to small scale seed potato farmers with minimum conditions to further multiply three generations (3G) or even certified potato seed.

Small Scale Farmers are the main potato producers in SSA however, they rarely participate in SPM in the seed potato value chain due to limited knowledge and acreage a requirement for participation by Kenya Plant Health Inspectorate Society (KEPHIS) a seed production regulatory body in Kenya, yet they are the main potato producers (Taiy Onyango &Nkrumwah,2017). There, is limited availability and access to quality seed, SSFs have tended to rely on informal seed potato systems which lead to low yields (Namugga, *et al*, 2017). Seed potato multiplication is done mainly by large scale farmers and private companies who do not produce enough seed to satisfy the demand (Ministry of Agriculture, Livestock and fisheries [MOALF], 2018). Out of the total certified potato seed requirement (800MMT) only 2.6% (208MMT) is produced by five centralized organizations (National Potato Council of Kenya, [NCPK] 2017). Due to high demand and lack of quality seed potato, growers multiply 6 or 7 times or even more which leads to extreme degeneration of seed (Okello *et al*, 2016). The need for quality seed is so high to the extent that small scale farmers who are the main potato producers seek for alternative ways of getting seed potato in Nakuru County (MOALF, 2018). Limited availability of quality seed potato is one of the many factors that lead to poor yields.

The farmer saved seeds are normally of low quality, premature and most of the time disease infested leading to low production (Campos & Ortiz, 2020). The cost of certified seed in Nakuru County is high due to high demand and low supply with prices ranging between Ksh 2,500/= to ksh3200/= per 50kg bag (MOALF, 2018). This could provide opportunities for small scale farmers' participation in the seed potato value chain, to multiply the seeds for food security and to generate incomes. Only 18.6% of all small- scale farmers participated in the seed potato value chain (SPVC) however they could play the role of decentralized multipliers (Oywaya-Nkurumwa *et.al*; 2018). This could be adequately achieved by provision of knowledge and skills on SPM to ease access of production inputs and networking (Tadesse et al., 2020). This was the gap that this study seeks to narrow down and intended to establish and utilize a shared learning platform for building small scale farmers' capacity to participate in seed potato multiplication. The platform aimed at increasing knowledge and skills that will hopefully increase participation of small- scale farmers in seed potato multiplication for increased availability and accessibility of quality seed

The SLP as an intervention for small scale farmers' participation in the seed potato value chain for seed multiplication. fits well in the actor- oriented change Chindi *et al*, 2016). The study used a shared learning platform to bring about change in the knowledge and skills required for participation in potato seed multiplication. The SSFs were involved in the change since they participated in the whole process from problem identification to solution implementation.

Figure 1: Relationship between variables



2.0 Methodology

Survey Research and Participatory Action Research designs. Simple Random Sampling was used to select 120 small-scale potato farmers to participate in a survey. The stakeholders were purposively selected from their organizations. Twenty-five farmers were purposively selected from those who participated in the baseline survey to participate in SLP and implement SPM practices. Data collection was done using a structured questionnaire, key informant interviews (KII) and Focus Group Discussion (FGD) guides. The information collected was organized, checked and validated with information from the baseline survey, key informant interviews, focus group discussions, personal observation of the researcher and action learning as per the objectives, research questions and the theoretical framework. Qualitative data was continuously collected throughout the SLP intervention period and analyzed through Thematic Content Analysis Quantitative data analysis was done using

STATA 2013 specifically for descriptive studies, the statical tests performed included; Z-test, T- test, Chi square at significance level = 0.05 and linear regression was also run.

3.0 Results and Discussion

The study investigated the influence of the Shared Learning Platform on seed Potato multiplication participation by small- scale farmers by testing the hypothesis that: Ho: There is no statistically significant influence of the SLP on participation in seed potato multiplication by small- scale farmers. To predict the influence of the SLP network on seed potato multiplication, a stepwise Multiple Linear Regression of the form y = a+b1x1+b2x2+b3x3 was used to evaluate whether network quality (NQI), capacity building of farmers (CBI) and knowledge sharing (KSI) mean scores could predict seed potato multiplication index (SPMI). The results of the model are summarized in Table I, Table II and Table III.

Table I: Model summary of multiple linear regression between SLP characteristics and Participation in seed Potato multiplication adoption strategies

					Change statistics				
Model	R	Adjusted R Square	Std Error of Square	R square Estimate	F change	Sig F change	df1	df	Durbin Watson
1	.894a	.800	.796	.2183	.800	191.9	1	48	.000
2	.940b	.882	.887	.1694	.083	33.03	1	47	.000
3.	.960c	.920	.913	.14206	.036	20.55	1	46	.000

a. Predictors: (Constant), Capacity Building Index
b. Predictors: (Constant), Capacity Building Index, Knowledge Sharing Index
c. Predictors: (Constant), Capacity Building Index, Knowledge Sharing Index, Network Quality Index
d. Dependent Variable: Participation in seed potato multiplication Index

Table 2: Anova table for multiple linear regression

Model	Sum of square	df	Mean of square	F	Sig
1. Regression	9.142	1	9.142	191.897	.000 a
Residual	2.287	48	.048		
Total	11.429	49			
2. Regression	10.085	2	5.043	176.877	.000b
Residual	1.343	47	.0289		
Total	11.428	49			
3. Regression	10.500	3	3.500	173.441	.000c
Residual	.928	46	.020		
Total	11.428	49			

a. Predictors: (Constant), Capacity Building Index
b. Predictors: (Constant), Capacity Building Index, Knowledge Sharing Index
c. Predictors: (Constant), Capacity Building Index, Knowledge Sharing Index, Network Quality Index
d. Dependent Variable: Seed Potato Multiplication Participation Index

Table 3: Regression coefficients

Model	Unstandardized Coefficients B	Std. Erorr	Standardized Coefficient Beta	t	Sig
1. (Constant)	.908	.191		4.722	.000
Capacity building index	.765	.055	.894	13.852	.000
2. (Constant)	.507	.166	3.390	.003	
Capacity building index	.476	.064	.564	7.404	.000
Knowledge Sharing Index	.395	.069	.438	5.747	.000
3. (Constant)	.530	.138		3.830	.000
Capacity Building Index	.321	.064	.380	5.021	.000
Knowledge Sharing Index	.296	.062	.328	4.793	.000
Network Quality Index	.235	.052	.335	4.533	.000

a. Predictors: (Constant), Capacity Building Index
b. Predictors: (Constant), Capacity Building Index, Knowledge Sharing Index c. Predictors: (Constant), Capacity Building Index, Knowledge Dissemination Index, Network Quality Index
d. Dependent Variable: Seed Potato Multiplication Participation Index

From the Multiple Linear Regression results, the following model was constituted for the influence of the Shared Learning Platform on seed potato multiplication practices adoption strategies by small-scale farmers. CCAI = 0 + 0.894CBI + 0.438KSI + 0.335NQI. Capacity building is the most significant independent variable as it is an important means for farmers to gain knowledge on new technologies. Capacity is the ability to fulfill a task or meet an objective effectively for enhancing participation of small-scale farmers in seed multiplication (Chikaire *et al*, 2015). In a systems perspective capacity building is not a one-off intervention, but a continuous process of upgrading and change (Mbaabu & Hall, 2012). The study also revealed that learning-by-doing, reflection and

adoption as key elements of capacity building. It also entails establishing innovation platforms to connect ideas with opportunities (Nederlof et al., 2011). Capacity building in the SLP by Egerton University, ADC Molo and the Kuresoi North Sub County Department of Agriculture enabled farmers to access knowledge on seed potato multiplication practices and technologies, get linked to seed sources and institute processes towards collective marketing of their seed potato.

Knowledge sharing within and outside the SLP is the second most significant characteristic in Seed potato multiplication participation. It popularizes the innovation by providing necessary information, knowledge and skills in order to enable farmers to apply the innovation (Bauer & Karki, 2004). There should be an exchange of knowledge between all stakeholders, including farmers and researchers (Quaraish, 1996). Knowledge Sharing within the SLP brings in the aspect of modern science mixed with indigenous knowledge in order to come up with appropriate seed potato multiplication practices for small -scale farmers participation. The study realized that Social Network Quality plays a significant role in seed potato practices adoption (Hall,2006). Farmers are more likely to adopt a technology when other farmers in their social network have adopted because they expect to share information, learn from each other and solve problems together (Banderia & Rasul, 2003). Technology adoption has been one of the mechanisms through which social networks are posited to have an important effect on agricultural decisions (Munshi, 2004).

4.0 Conclusions

From this study, we conclude that the key determinants for SLP functioning for the SPM practices adoption for participation requires stakeholder participation, quality networks, knowledge sharing, reflection, capacity building resource mobilization, commitment and ownership. Interactions of small -scale in the shared learning platform. Networks would create opportunities for farmers empowerment for collaborations and interaction. Promotion of shared learning platform innovation would address the challenges farmers face in participating in seed potato multiplication. Capacity building in SLP is an important means for farmers to gain knowledge information on seed potato multiplication practices and technologies adoption. This occurs when farmers interact with other stakeholders to network and innovate for knowledge generation on seed potato Multiplication practices adoption as this enables seed potato value chain actors to share information, learn from each other and solve problems together. It is key in technology dissemination since farmers are likely to adopt a technology when other actors in their social network have adopted it. After the intervention 10 SSFs donated more than one acre for seed potato multiplication as per the KEPHIS for the next season as a group since they qualified as per KEPHIS regulation

5.0 Recommendations

Our study recommends that it is necessary to have a centralized coordination mechanism for small scale farmers participation in seed potato multiplication for the availability of certified seed and as a way of mitigation of shortages as well as the adoption of the necessary practices and implementation in seed potato value chain by small scale farmers. This will entail putting in place policies and institutions that will address and prepare the country to address the challenges experienced by small scale farmers in seed potato multiplication for availability of certified seed potato. There is a need for coordinated effort to enhance seed potato multiplication by small scale farmers. There is need for the researchers and the extension agent to be conversant with the identified farmer socio -economic characteristics which may influence their participation in seed potato multiplication and improve farmers' capacities for the involvement to reduce risk or make optimal use SPM practices for

availability and access of certified seed potato for increased production and incomes. This can be achieved through applying participatory research and extension activities for up scaling of SPM practices adoption strategies developed collaboratively by actors using a Shared Learning Platform. To bridge the existing deficit in certified potato seed, small-scale farmers should be trained on certified seed potato multiplication techniques such as site selection crop management and postharvest handling for certified seed positive and negative selection. This would ensure timely access to certified seed potato by farmers at a more affordable price. Small- scale farmers need to form groups, cooperatives and engage in contract farming in order to overcome technological and market constraints. Collective marketing of farm produce and acquisition of inputs enable the farmers to negotiate prices in order to benefit from the economies of scale. Cooperatives facilitate bulking of farm produce for access to niche markets.

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Antifungal Effects of Selected Bio-Controls Against *Rice Blast Fungus (Magnaporthe Oryzae)*

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Abstract

Rice blast caused by *Magnaporthe oryzae* is a devastating fungal disease of rice globally affecting all plant parts and seeds. Use of fungicides is the major management method of the disease; however, fungicides have negative impacts on environment and human health. The objective of this study was to determine the potential efficacy of *Trichoderma* isolates, BG-1, SYA-E, BRO-2, SYA-C, EM-B and vermiwash against rice blast fungus *(M. oryzae).* The assay was carried out in the laboratory in a Completely Randomized Design (CRD) with three replications. *M. oryzae* fungus was isolated from naturally infected rice tissues of variety ITA-310 in west Kano irrigation scheme by sporulation of the pathogen on a moist chamber and then streaked on 2% water agar media and cultured for five days. Both *Trichoderma* and *M. oryzae* isolates were cultured in PDA (Potato Dextrose Agar) for 7 days and inhibition tested using dual culture method. A disc plug of 8 mm radius of *M. oryzae* and 5 *Trichoderma* isolates were picked from the periphery of the mycelium and placed 7cm apart in 9cm PDA plates under aseptic conditions. Rice straw vermiwash harvested after 14 days from the vermicomposting structure and diluted to 10% was streaked at the edge of the agar plate with a test pathogen aseptically. The inoculated petri dishes were incubated at 25±2 ºC and data on radial growth in mm of the 5 *Trichoderma spp* and vermiwash against M. oryzae colonies was collected at 48hrs, then after every 24hrs for 7 days. The 6 bio controls were significantly different for antifungal activity at $p \leq 0.0001$. However, the control was significantly different to all the biocontrol's at $p \leq 0.05$. The biocontrol that exhibited the highest antifungal activity against M. oryzae were Vermiwash, EM-B, SYA-C, and BRO-2 with inhibition of 72.81%, 71.49% and 71.05%, respectively exhibiting potential to be used as controls for rice blast disease. Additional research of the selected best performing *Trichoderma* isolates and vermiwash need to be evaluated under green house and field experiments to suppress rice blast disease for enhanced rice productivity.

Key words; Vermiwash, Biocontrol, Invitro, Isolates, Rice Blast

INTRODUCTION

Suppression of diseases is a biological process involving interaction of the host plant, pathogen and the environment. Different strategies can be used individually or in combination with others in a view to manage the plant diseases (Manivannan *et al.*, 2012.).Chemical pesticides and fungicides have been extensively used for control of the diseases and pests successfully however; a shift in the attitude towards use of this chemical products in agriculture due to strict regulation on some fungicides, miss use of the chemicals, residue left overs on the crops and spread of diseases to natural ecosystem have been noted.

This has prompted researchers to focus on finding alternatives to synthetic chemicals in controlling pest and diseases referred to as biological controls. Biocontrol's are based on plant parts /products, microorganism such as bacteria viruses and fungal and bacterial enzymes inhibitors (Manivannan *et*

al., 2012.). They are cost effective; give protection throughout the cropping period, effective in controlling specific plant diseases, less toxic to plants and safe to the environment. Fungus *Magnaporthe oryzae* is a devastating air borne pathogen that attacks rice at all stage of growth infecting the aerial parts of the plant (Mutiga *et al.,* 2017). The disease is managed by use of fungicides such as carbendazims, benzoyl, and tricocyclazole among others however; these chemicals have diverse effect on the environment, human health as well as development of resistance by the pathogen. Biological control of rice blast fungus majorly relies on use of antagonistic mycoparasites and induction of host plant resistance.

Trichoderma *sp* are key biocontrol agents of plant pathogenic fungi also known as mycoparasites with a potential to directly affect fungal pathogens and induce resistance in plants. Over 300 different species of Trichoderma have been morphologically and genetically identified, and known to spread widely over different ecosystems. This mycroparasite have gained popularity as a biocontrol because of: secretions of lytic cell wall degrading enzymes CWDE`s, root nutrient competition and induction of systemic resistance in plants. Crude extracts of Trichoderma isolates indicated antimicrobial activities towards spore germination of all plant pathogenic fungi.(Tamandegani *et al.,* 2020)
Vermiwash a by-product of vermicomposting has exhibited potential in its application as a biocontrol agent against pest and disease (Che Sulaiman & Mohamad, 2019). Other studies have proved that organic amendments when applied to plants induces resistance of some pest attacks and disease resistance compared to synthetic fertilizer (Arancon *et al.,* 2005).

Past studies have shown that major factors determining efficacy of compost vermiwash in inhibiting progression of plant disease is their composition of microbial communities linked to organic wastes (Fernández-Gómez *et al., 2011).* Vermiwash has microorganisms that can suppress plant diseases through complex mechanism like antibiosis, competition through production of massive siderophores, induce systemic resistance (ISR) as well as acquired systemic resistance (ASR). (Mehta *et al.,* 2014)
Consistent performance of vermiwash was noted on a number of trials over a wide condition of the rhizosphere, however, minimum research have been conducted against foliar plant pathogens. Therefore, studies of foliar spray of vermiwash against foliar plant pathogens needs further validation (Khan et al., 2015).

Material and methods

Collection of fungal spores from rice blast diseased leaves in the field.

Sampling of the paddy fields was done in West Kano and Busia counties where naturally infected leaves were identified and collected. The infected rice tissues carefully packed in dry brown, small sized coin envelopes and taken to the laboratory for preservation and isolation. Water agar (WA) solid medium (2%) was prepared by dissolving 20g of agar powder in 1000 ml of water, autoclaved at 121^0C for 15 minutes and cooled down to 50°C. 12mls of the media was dispensed into 6-cm-diameter plastic dishes waiting for isolation process. Rice bran agar and 2% water agar media was prepared by mixing 1000 ml of water with 20g rice bran and 20g of agar powder, autoclaved and cooled down to 50°C. Approximately 12 ml of the media was dispensed into 6-cm-diameter plastic petri dishes and allowed to solidify in readiness for sporulation of the fungus.(FEI *et al.,* 2019). Rice blast fungus was isolated from infected rice tissues by sporulation of the pathogen on a moist chamber and then streaked on 2% water agar media. Spores were identified by observing lesions of the diseased rice tissues using a dissecting microscope in a laminar airflow hood. A single spore was picked with a sterile wire loop, put in plates containing water agar media and incubated for 7 days at 25^{o}C until germination. The germinating single spores of 4mm^2 was cut and transferred into petri dish containing Rice Bran Agar

(RBA) media. Under a sterile condition in a laminar airflow hood, steel forceps was used to pick 5 pieces of sterilized Whatman filter paper cut into $2mm^{2,}$ and put around the germinating spores. The petri dish was containing the pathogen was incubated at an average temperature of 25 ºC with a 12-hour photoperiod for 21 days. The colonized Whatman filter papers were peeled off from the media, placed on lidded plastic container containing silica gel desiccant for 10 days at room temperature to dry. The dried filter papers containing the fungus were put in sterile coin envelops inside a lidded plastics and stored at -20^{o}C for future use.

Determination of antifungal effects of the six-biocontrol agents on *M. oryzae* was conducted at KALRO-Sugar Research Institute in Kisumu County. The biocontrol comprised 5 *Trichoderma* spp and rice straw vermi juice at 10% dilution. The assays were carried out in the laboratory and layed out in a Complete Randomized Design (CRD) with 3 replications. *M. oryzae* isolate and the biocontrols were cultured in Potato Dextrose Agar (PDA) for 7 days and inhibition tested using a dual culture method. Using a sterile cork-borer, 8 mm disc plug of *M. oryzae* and the *Trichoderma* isolates were picked from the periphery of the colony and placed 7cm apart in a PDA plates (9cm in diameter) under aseptic conditions. The inoculated petri dishes were further incubated at 25±2 ºC temperature and radial growth of *M. oryzae* colonies measured after 7days. Vermiwash was collected from the vermicomposting structure after 14days and diluted to 10%, streaking was done at the edge of the agar plate with a test pathogen in a laminar airflow chamber. The petri-dishes with the test pathogen were put in the growth chamber at 25 ± 2°C, with 12 h day/night cycle. The diameter of the *M. oryzae* colony was measured at 48 and 72 hrs after inoculation according to Akinnuoye-Adelabu *et al* (2019).

After 21 days of incubation at 25^{o}C with 12-hour photoperiod plate culture of *M.oryzae* were colonized by the fungus and a dusty grey appearance mycelium seen to have grown occupying the culture plates and the Whatman filter papers (Zewdu, 2021). About 3ml of distilled and sterile water was added on the 21 days dish with *M.oryzae* and plastic cell scrapper was used to gently harvest mycelium and fungal conidia for observation. Conidial cell count/concentration was performed using a hemocytometer and biological microscope at a 100-magnification. Observed was a conidiophore that appeared swollen with a fusiform shape with 2 septet and translucent colors. (Zewdu, 2021)

Figure 2: *Dusty grey mycelial growth on petri dish and germinated single M oryzae spore observed under microscope*

A total of the 6-biocontrol agents comprising of five *Trichoderma* isolates identified as BG-1, SYA-E, BRO-2, SYA-C, EM-B and vermiwash were tested for antifungal activity against rice blast fungus

M. oryzae. These micro-organisms are documented as having potential to inhibit the growth of several fungal plant pathogens including *Pyricularia spp.* The radial growth of the colony was compared against the controls and the antagonistic effect of the selected biocontrol agents against *M.oryzae* calculated according to (Yadav, 2018)

$$\text{percentage inhibition, } PI\ (\%) = \frac{C - T}{C} \times 100\%$$

Where, PI= C = Pathogen radial growth in cm in control; T = Radial growth in cm in treated plates.

RESULTS AND DISCUSSIONS

Out of the 6 bio controls agents 2 of them Vermiwash at (72.9%) and one *Trichoderma* isolate EM-B (71.3%) showed maximum inhibition *against M..oryzae* and further carried forward to green house and field experiments. The rest of the four isolates exhibited different degrees up to 71.01% of growth inhibition as shown in table 1 below.

Table Percentage growth inhibition or *Trichoderma* isolates and Vermiwash against rice blast fungus *(Oryzae*). Results indicate mean of the three replications with standard deviation

SNo	Biocontrol	Radial Growth(mm)	% Growth Inhibition	
1	BG-1	7.11 ±0.057	70.8±	B
2	SYA-E	7.17±0.193	68.4±	B
3	BRO-2	7.11±0.840	70.08±	B
4	SYA-C	6.64±0.0918	71.01±	B
5	EM-B	6.51±0.0154	71.3±	B
6	V. JUICE	6.16±0.0750	72.9±	B

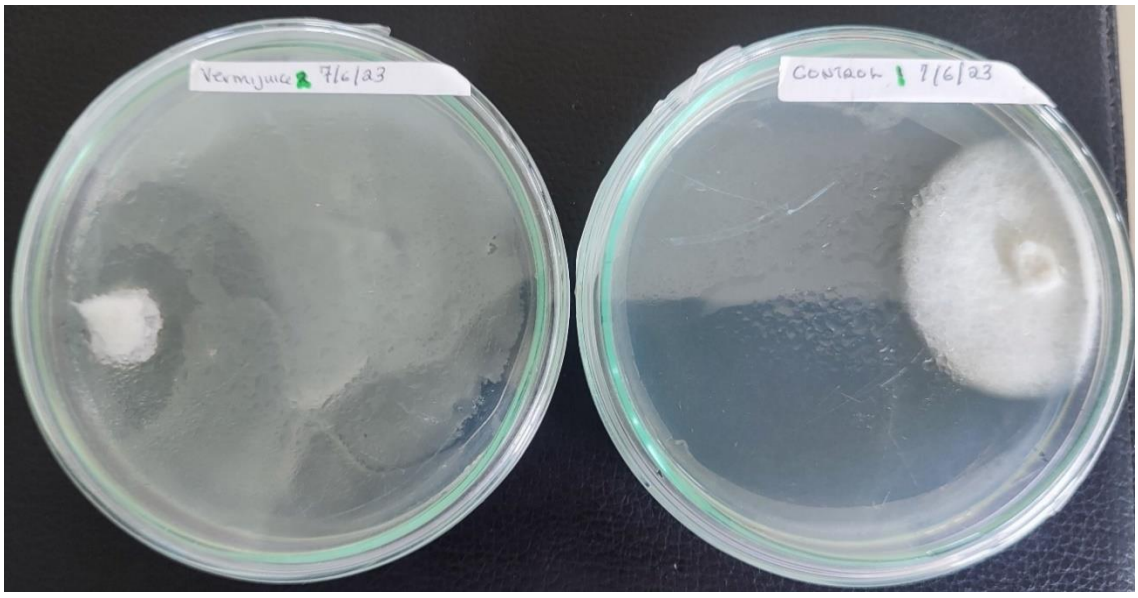

Figure 3: *Dual culture assay of M.oryzae streaked with vermiwash*

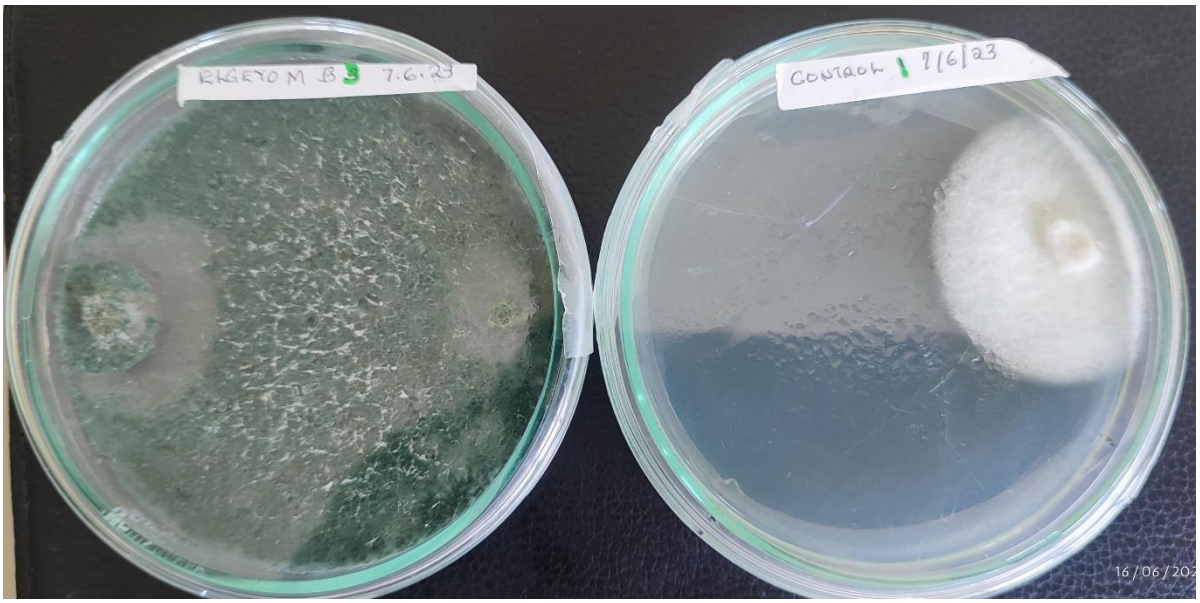

Figure 4: *Dual culture assay of M.oryzae with Trichoderma isolate EM*

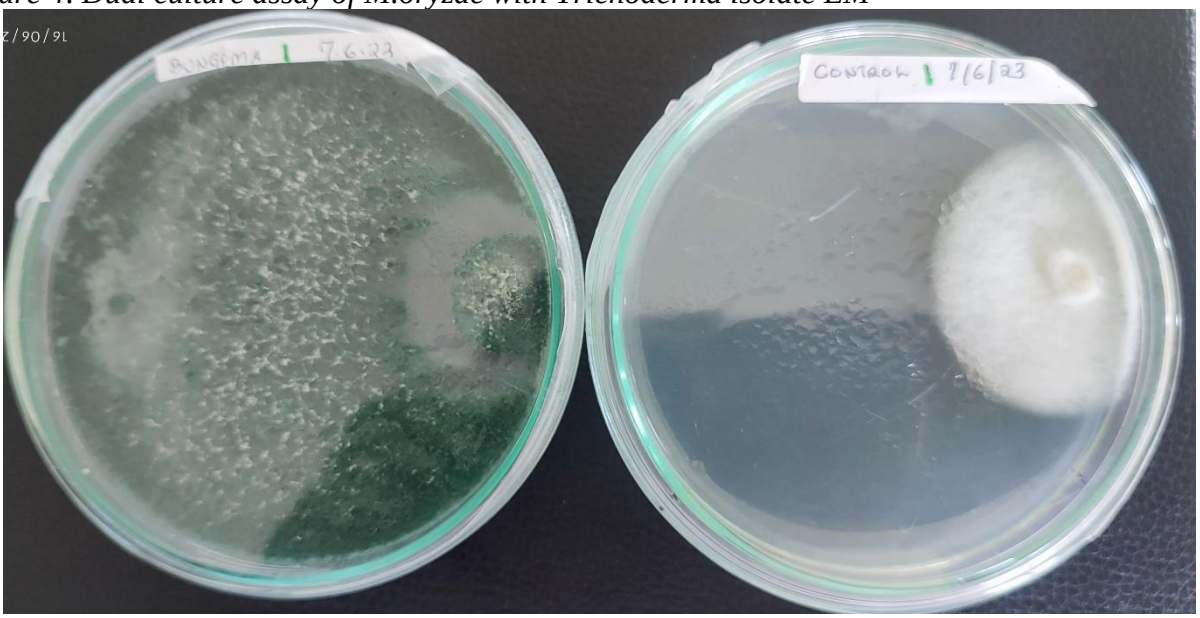

Figure 5: *Dual culture of M oryzae with Trichderma isolate BRO*

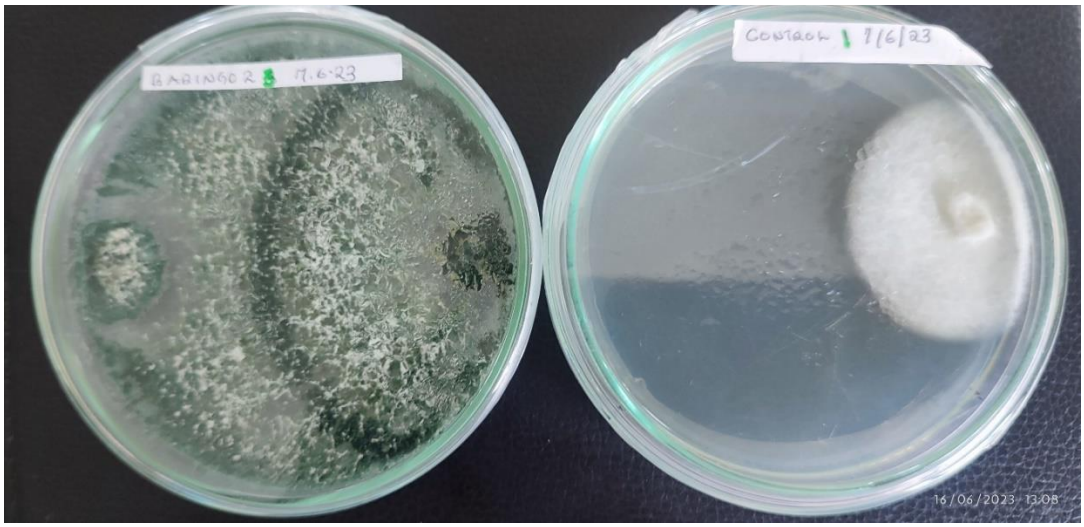

Figure 6*: *Dual culture of M oryzae with Trichderma isolate BRO2

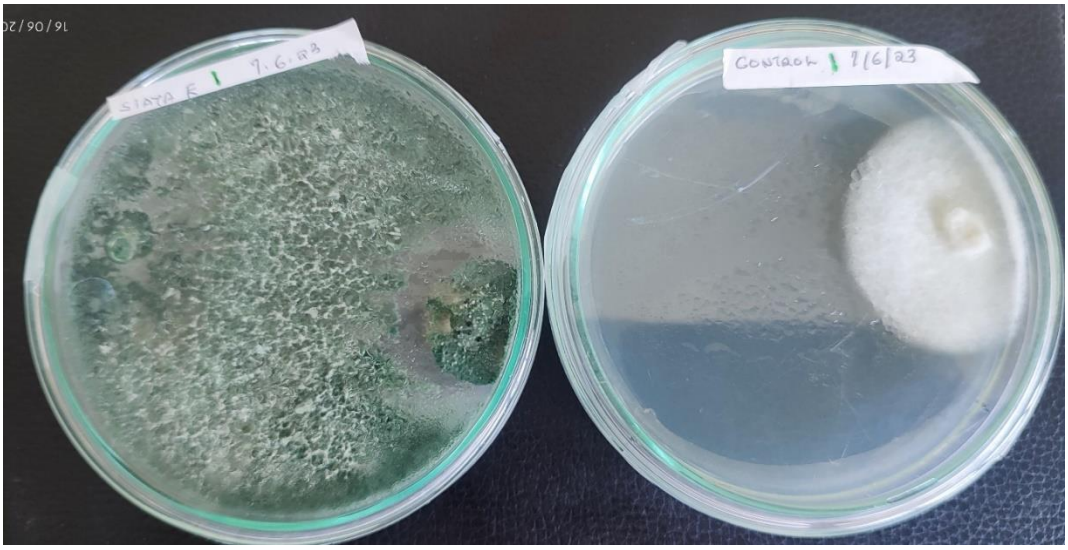

Figure 7*: *Dual culture of M oryzae with Trichoderma isolate SYA-E

DISCUSSION

The study was conducted to evaluate the effectiveness of *Trichoderma Spp* and rice straw vermiwash on invitro growth of rice blast fungus *Magnapothe oryzae.* The findings revealed that Trichoderma EM-B isolates and rice straw vermiwash exhibited a high potential of inhibiting the growth rice blast fungus *M.oryzae* under laboratory conditions. These findings are in agreement with studies conducted on vermiwash indicating that the presence of beneficial micro biota boosts plant growth through production of plant growth enzymes and hormones that indirectly suppresses plant pest and diseases (Gudeta *et al*., 2021), Vermiwash exhibited an ability to control bacterial and fungal phytopathogens both invitro and in-vivo according to (Yadav, 2018). Application of vermiwash on above ground parts of plants as foliar spray and below ground as soil drench have been studied to understand the mechanism behind suppression of plant pest and diseases. It is recorded that vermiwash contains enzymes, nutrients and other secretions of the worms that suppress the pest when used as a foliar

application (Joshi *et al*., 2015). Other invitro studies have shown the effect vermiwash on common fungal and bacterial phytopathogens, two bacterial isolates from vermiwash identified as *Bacillus sp* and *Burkholderia sp* exhibited a significant zone of inhibition against fugal phytopathogens like *Fusarium solani* in Brinjal,*alteraria, solani* in tomato. that were isolated from diseased leaves and seeds of various plants(Pattnaik *et al*., 2015). Vermiwash has the potential to suppress both foliar and root pathogen in cucumber and tomato where various concentration of vermiwash were drenched into the growth medium and found to significantly suppress damage of root by the pathogen *Fusarium oxysporum.*

CONCLUSION

Rice straw vermiwash and EMB *Trichoderma* isolates were found to be the most effective biocontrol agents against *M oryzae* phytopathogen. The two biocontrol agents exhibited the potential against rice blast diseases invitro and were selected for further trials in the green house and field experiments

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Fall Armyworm (Spodoptera Frugiperda) Infestation on Advanced Sorghum Genotypes Under Field Conditions in Arid And Semi-Arid Areas in Kenya

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Abstract

Fall armyworm (FAW) (*Spodoptera frugiperda)*) continues to cause enormous losses in Sorghum and other cereals in the world. Excessive use of synthetic insecticides to manage the pest poses environmental hazards. The objective of this study was to screen several sorghum genotypes against FAW. A total of 49 sorghum breeding lines from Genetic Resources Research Institute (GeRRI), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were screened for FAW resistance. The study was carried out in Koibatek Agricultural Training Centre (ATC) during the 2018/2019 long/short rain seasons. The experiments were laid out in *Alpha lattice* design, 49 x 7, and replicated three times. Sorghum was planted, at a spacing of 75 cm x 20 cm with 3 rows in 2.5 m by 1.5 m plots. Data was collected on larval counts (LC) and grain yield (tons ha^{-1}). Data was subjected to analysis of variance using Statistical software (SAS) version 9.2. Statistical differences among the treatment means for all the variables were compared using LSD test at $p \leq 0.05$. Results indicated that grain yield was 0.88tons ha^{-1} during the first season and 2.44 tons ha^{-1} during the second season. Higher larval count was observed during the whorl stage compared to seedling stage. Mean larval count ranged between 2.90 and 4.49 $plant^{-1}$ during season one and two in Koibatek, ATC. Genotypes GBK - 001103, GBK - 000121 and GBK 000392 had low larval count as well as high yields. Results of this study shows there are promising sorghum genotypes that are tolerant to fall Army worm which can be used in sorghum breeding programs.

Key words*: Fall armyworm, sorghum bicolor, Host plant resistance, Host plant damage, screening for resistance, Biocontrol*

1.0 INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench is a drought tolerant crop that can provide food security in Arid and semi arid areas (ASALs) (USDA, 2017). This potential has however been threatened by biotic and abiotic factors. Biotic factors limiting sorghum production include pests amongst them, Fall army worm (FAW) (*Spodoptera frugiperda* J.E. Smith) (*Lepidoptera Noctuidae*). Fall army worm a native to South America is a new pest first reported in Africa in 2016 in Nigeria, Sao Tome and Togo (Georgen *et al*., 2016). The pest has now spread to Africa, Asia, Europe and Australia (Shylesha *et al*., 2018; Maino *et al*., 2021; Wang *et al*., 2023). Grain yield losses ranging between 22 and 67% have been reported in African countries (Day *et al*., 2017; Kumela *et al*., 2018; De Groote and Bruce, 2020; Kassie, 2020). Factors that cause the successful dispersal and invasion of the FAW is its ability

to produce large number of eggs, fly long distances as well as ability to feed on large number of plant crops species though cereals such as maize and sorghum are the major hosts.

Since FAW invasion in 2016, African governments have invested heavily on registered Synthetic insecticides to manage the pest. However, farmers apply high doses (Otim *et al.,* 2020) posing environmental hazards and increased cost of production. Ability of the young larvae to feed at night and hide in the funnel during the day time reduces the effectiveness of the chemicals especially the contact insecticides. There is also high risk of developing resistance to some insecticides molecules (Zhang *et al*., 2021 and Liu *et al.,* 2019). Recent studies in Africa have reported numerous association of FAW with egg, larval and pupal parasitoids such as *Telenomous spp, Trichogramma spp, Cortesia spp, Chelonus* spp (Sisay *et al*., 2018; Laminou *et al.,* 2020; Agboyi *et al*., 2020; Otim *et al*., 2021; Ahissou *et al.,* 2021) but more studies on their effectiveness needs to be carried out. Predators such as Ants (Pheidole spp), beetles (*Cheilomenes* spp), Earwigs (*Doru* spp) (Koffi *et al.,* 2020; Malo and Hore, 2020 and Ahissou *et al.,* 2021) have also been reported in Africa but more studies on their abundance and level of predation needs to be carried out. Entomopathogenic or disease causing organisms such as Fungi, Viruses, and Nematodes are available in the soils and could manage FAW. Studies on Entomopathogens such as *Bacillus thuringiensis*, *Beauveria Bassiana*, *Metarhizium anisopliae*, *Nomuraea rileyi* and *Spodoptera frugiperda multiple* Nucleopolyhedrosis virus (SfMNPV) have been carried out (Akutse 2020; Rajula *et al*., 2021; Russo *et al*., 2021; Fallet *et al*., 2022) but more efficacy studies in the field need to be carried out. Effectiveness of the Entomopathogens is also highly influenced by the environment. Nucleopolyhedrosis viruses (NPV) are highly denatured by ultraviolet light. Plant derived pesticides possess compounds which act as toxicants, antifeedant, repellents or growth inhibitors on insect pests. Neem based *Azadirachta, Tephrosia Vogelii* among others have been reported to manage several insect pests (Ogendo *et al.,* 2008; Tavares *et al*., 2010 and Mukui 2013) but only limited field efficacy trials have been carried out on FAW.

Use of resistant sorghum genotypes provides a sustainable management option to manage FAW in sorghum production. Fall armyworm resistant maize lines and Hybrids have already been developed (Prasanna *et al*., 2022) in the background of Maize stem borers resistant traits but only limited research work has been done on sorghum. Use of FAW resistant sorghum genotypes in combination with other FAW management strategies would constitute a tailor made IPM package suitable within an individual farming system and capability of the farmer for sustainability. This study aimed at identifying and validating levels of host plant resistance in currently available Kenyan adapted sorghum germplasm. Forty-nine (49) advanced sorghum lines from Genetic Resources Research Institute (GeRRI), and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were evaluated against FAW infestation and associated grain yield losses for two seasons in 2018/2019 in Koibatek ATC (Agricultural Training Centre) in Baringo county. The identified FAW tolerant and high grain yield sorghum lines will be used by breeders to improve sorghum production.

2.0 MATERIALS AND METHODS

2.1 Experimental site

This study was conducted in Koibatek Agricultural Training Centre (ATC), in Baringo County, Kenya. Koibatek is a medium altitude zone with an altitude of 1890 m A.S.L in Agro-ecological zone UM4, with low agricultural potential. The station lies within longitude 36º 66' E and latitude 10º 35' S. Average annual rainfall is 767 mm; mean annual minimum and maximum temperature are 10.9ºC and 28.8ºC respectively. Soils are Vitric Andosols with moderate to high soil fertility and well drained deep to sandy loam soils (Jaetzold and Schmidt, 2011).

2.2 Study Germplasm and Experimental design

This study involved evaluation of 49 sorghum advanced genotypes from Genetic Resources Research Institute (GeRRI), The experiment was carried out for two seasons during May – October 2018 and 2019 in Koibatek. The test entries were planted in three replicates using 49 x 7 *Alpha lattice* experimental design. Each plot consisted of three rows, measuring two meters in length, spaced 75cm between rows and 20cm intra row.

2.3 Data Collection

Fall army worm larval Count during seedling (V3) and whorl stages (V6): The number of larvae plant $^{-1}$ (Larval count) was assessed during the vegetative stage, 30 days after seedling emergence when there was infestation and at the whorl stages by pulling the whorl leaf from 5 infested plants selected randomly and unfolding the leaves to expose and count the FAW larvae (Anderson and Cherry, 1983). This was repeated after 10 days and was carried out three times during the whorl stage.
Grain yield (tons Ha^{-1}): Grain yield was obtained by harvesting the middle row per plot.

2.4 Data Analyses

Data on Fall army worm larval count was transformed using square root transformation before being subjected to ANOVA using Statistical software (SAS) version 9.2. Treatment means for transformed data were separated using LSD ($p \leq 0.05$).

3.0 Results

3.1.3 Fall Army worm Larval count

Results from this study showed significant ($P \leq 0.05$) genotypic variation for both larval count (grain yield in Koibatek, ATC during seasons one (2018) and two (2019) (Table1.0). Higher grain yield was observed in season one, 2.44±0.07tons ha^{-1} compared to season two, 0.88±0.03 tons ha^{-1}. Genotypes GBK-001103 and GBK-000121 had the highest grain yields (2.29, 2.14 tons ha^{-1} during seasons one and two respectively), compared to susceptible check, KARI Mtama 1 (0.05 tons ha^{-1}, 1.62 tons ha^{-1} during seasons one and two respectively). GBK-000392 had higher grain yields of 4.19 tons ha^{-1} during season one compared to season two, 2.86 tons ha$^{-1.}$ Higher larval count was observed during the whorl stage (V6), (4.49±0.14, 2.94±0.13 larvae plant^{-1} during seasons one and two respectively) compared to seedlings stage V3, (3.09±0.11, 2.90±0.08 larvae plant^{-1} during seasons one and two respectively), Table 1.0. Higher larval count was observed during season one in (3.09±0.11, 4.49±0.14 larvae plant^{-1} during seedlings stage (V3) and whorl stage (V6) respectively compared to season two (2.90±0.08, 2.94±0.13 larvae plant^{-1} during seedlings stage (V3) and whorl stage (V6) respectively). Genotype GBK- 001103 had low larval count (2.33, 3.33 larvae plant $^{-1}$ during seedling stage (V3) and whorl stage (V6) respectively) compared to susceptible check, KARI Mtama 1 susceptible check (3.33, 6.67 larvae plant^{-1}). Similar low larval count (2.33, 1,33 larvae plant $^{-1}$) was observed during season two for this genotype. (Table 1.0).

Table 1.0: Fall army worm, larval count, and grain yield of selected sorghum breeding lines in Koibatek, Kenya (2018/2019)

	Season one May /October 2018			**Season two (2019) May/October 2019**		
Genotype	**Larval count (larvae plant^{-1})**		**Yield (tons ha^{-1})**	**larval count (larvae plant^{-1}**		**Yield (tons ha^{-1})**
	Seedling stage(V3)	**Whorl stage(V6)**		**Seedling stage(V3)**	**Whorl stage(V6)**	
GBK-001103	2.33^{defg}	3.33^{efgh}	2.29^{a}	2.33^{defg}	1.33^{f}	2.33^{fghi}
GBK -000121	1.67^{fg}	5.67^{abcd}	2.14^{ab}	1.67^{fg}	2.33^{cdef}	2.37^{fghi}
GBK-037565	1.33^{g}	4.33^{bcde}	1.67^{cdef}	1.33^{g}	2.0^{def}	2.48^{fghi}
GBK-044672	1.67^{fg}	5.00^{abcd}	1.53^{defg}	1.67^{fg}	2.0^{def}	3.2^{bcde}
IS 21055	2.67^{cdef}	3.33^{efgh}	1.30^{fghi}	2.67^{cdef}	1.67^{ef}	3.92^{abc}
GBK-000392	3.00^{bcde}	4.33^{bcde}	2.86^{klmn}	3.00^{bcde}	2.67^{bcde}	4.19^{ab}
KARI Mtama 1(SC)	3.33^{abcd}	6.67^{a}	0.05^{v}	3.33^{abcd}	4.00^{abc}	1.62^{nopq}
LSD (p≤ 0.05)	**1.64**	**2.05**	**0.47**	**1.89**	**1.97**	**1.08**
CV (%)	**24.55**	**21.19**	**24.02**	**30.3**	**30.97**	**20.6**
Mean ±SE	**3.09± 0.11**	**4.49±0.14**	**0.88±0.03**	**2.90± 0.08**	**2.94± 0.13**	**2.44± 0.07**
Source of variation						
Block (Group)	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
Genotype (GE)	**0.002**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**

KEY: Scoring scale, 1 to 9 scale, where score 1, <10% leaf area damaged, 9>80% leaf area damage, where 1-2 highly resistant, 3-4 resistant, 4-5 moderately resistant, 5-6 intermediate, 6-7 moderately susceptible, 7-8 susceptible, and 9-highly susceptible. SC=susceptible check; Yield=Grain yield tons ha^{-1}; SE = Standard error; GE=Genotype; means in the same column followed by the same letter are not significantly different (P≤.05); **NB:** Genotypes presented represent best performing and FAW resistant lines amongst 49 genotypes evaluated.

Discussion

There was a significant ($P \leq 0.05$) genotypic variation for both larval count and grain yield in Koibatek, ATC during seasons one (2018) and two (2019). This showed that FAW infestation and grain yield were largely influenced by the different genotypes. Higher grain yield during season two compared to season one could have been caused by low FAW larval infestation and larval count observed during that season. Very high larval count during season one was observed and could have resulted in low yields. A similar seasonal variation on FAW infestation was observed by Sisay *et al*. (2019) in Ethiopia, Kenya and Tanzania. Overall, higher larval count was observed during the whorl leaf stage (V6) compared to seedling stage (V3) in Koibatek during seasons one and two. As the season starts and progresses, there is a progressive build-up of pest population along the growth stages of the crop which also influence the level of infestation and damage. Fall Armyworm damage normally progresses during the growing season with small and tiny holes made by few young larval instars and this damage progresses further with larger lagged holes produced by many grown instar larvae (Venkateswarlu *et al*., 2018). Niassy *et al*. (2021) also reported a similar trend of high FAW adult and larval population during the vegetative and reproductive stage compared to maturity stage. Seasonal variation across seasons was also observed with high larval count during the first season in Koibatek compared to Second season in Koibatek. Lower larval count observed during the second season (May 2019/October 2019) in Koibatek compared to first season (May 2018/October 2018) could have been caused by heavy rainfall (Appendix 2) that could have washed and drowned the larvae in the funnels in Koibatek. Low temperatures observed during the second season could have reduced the larval count since their optimum temperature ranges between 26^{o}C and 30^{o}C (Du Plessis *et al*., 2020). Genotypes GBK-001103 and GBK- 000121 had low larval count and high yields during season one compared susceptible check, KARI Mtama one. Similarly GBK-000392 had high grain yield during season two. GBK - 037565 had low larval counts during seasons two.

Conclusions and Recommendation

Data from this study shows that Genotypes GBK-001103, GBK- 000121 and GBK - 037565 had low FAW infestation and high grain yields and could be tolerant to FAW infestation. GBK-000392 had high yields in season two compared to season one showing that it could be more stable in season two in Koibatek, ATC. Further field evaluations and validation of FAW resistance in High yielding and FAW resistant genotypes such as GBK-001103, GBK- 000121 and GBK - 037565 GBK-000392, should be carried out for further sorghum breeding improvements initiatives. More germplasm could also be evaluated to increase resistant genotypes and improve others resistance and agronomic traits.

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APPENDICES

Appendix I: List of Evaluated Germplasm

	Genotype	**Source**		Genotype	**Source**
1	GBK -000121	GeRRI	26	GBK-001106	GeRRI
2	GBK -000975	GeRRI	27	GBK-013089	GeRRI
3	GBK-000010	GeRRI	28	GBK-013122	GeRRI
4	GBK-000120	GeRRI	29	GBK-013132	GeRRI
5	GBK-000123	GeRRI	30	GBK-037565	GeRRI
6	GBK-000124	GeRRI	31	GBK-044625	GeRRI
7	GBK-000387	GeRRI	32	GBK-044647	GeRRI
8	GBK-000389	GeRRI	33	GBK-044653	GeRRI
9	GBK-000391	GeRRI	34	GBK-044672	GeRRI
10	GBK-000392	GeRRI	35	GBK-044693	GeRRI
11	GBK-000412	GeRRI	36	IESV 92036 SH	ICRISAT
12	GBK-000424	GeRRI	37	IESV 92042 SH	ICRISAT
13	GBK-000425	GeRRI	38	IESV 24029	ICRISAT
14	GBK-000426	GeRRI	39	IESV 92022/1 SH	ICRISAT
15	GBK-000444	GeRRI	40	IESV 92030 SH	ICRISAT
16	GBK-000445	GeRRI	41	IESV 92041 SH	ICRISAT
17	GBK-000446	GeRRI	42	IS 21055	ICRISAT
18	GBK-000447	GeRRI	43	IS 8193	ICRISAT
19	GBK-000936	GeRRI	44	IS2108	ICRISAT
20	GBK-000943	GeRRI	45	KARI Mtama 1	KALRO (COMMERCIAL)
21	GBK-000946	GeRRI	46	SIAYA-6-1	LOCAL
22	GBK-000973	GeRRI	47	WAGITA	LOCAL
23	GBK-000979	GeRRI	48	BUSIA 21	LOCAL
24	GBK-000983	GeRRI	49	BUSIA 30-3	LOCAL
25	GBK-001103	GeRRI			

Appendix 2: Weather data, ATC, Koibatek Weather station during the 2018/2019 growing season

Year	Month	Rain.mm	Max.Temp (0c)	Min Temp(0c)	Rel. Hum
2018	May	349.5	21.81	9.00	48.70
2018	June	45.8	28.20	10.50	43.20
2018	July	0	21.10	10.00	56.30
2018	August	324.2	19.20	10.00	58.80
2018	September	21.5	16.20	10.20	63.20
2018	October	125.8	15.20	9.00	65.40
2019	May	87.65	12.30	9.00	73.20
2019	June	402.5	10.20	8.00	61.00
2019	July	131.8	16.70	9.00	75.30
2019	**August**	**189**	22.10	10.00	60.40
2019	**September**	**167.9**	18.10	11.00	51.10
2019	**October**	**211.8**	22.30	12.00	60.80

Effects of Biofertilizers Farm Yard Manure on Soil Properties and Nutrient Uptake By Potato (*Solanum Tuberosum* L.)

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Abstract

Low soil fertility is the one of the constraints to sustaining agricultural production and productivity in Kenya. Soil fertility has often been regarded as soil's chemical and physical properties. The combined application of manures and biofertilizers plays a pivotal role in improving soil physico-chemical properties, uptake of macro and micronutrient distribution, and their transformations under different cropping systems. Using the microbial aspect is often being ignored in enhancing soil fertility. Therefore, Integrated nutrient management (INM) options utilize organic fertilizers and biofertilizer nutrients for sustainable agricultural production. This study was conducted to evaluate the effect of farmyard manure with biofertilizers (*Trichoderma asperellum*, T.R., and *Bacillus subtilis*, B.A.) on nutrient uptake by potatoes. Two field experiments were carried out using two potato varieties (*Shangi* and *Kenya mpya*) during the 2019 and 2020 seasons. The treatments were; 30 t ha^{-1} of farmyard manure (FYM), two different biofertilizers (TA and BA) applied at the rate of (150 mL/10 kg) and NPK (0 and 100 kg ha^{-1}) as negative and positive controls, respectively. Field experiments were conducted using a randomized complete block design in a split-plot arrangement. The result indicated that all treatments affected the soil physicochemical properties. However, there were no significant differences before and after harvesting. The significant uptake of both macronutrients and micronutrients was recorded by using FYM at 30 t/ha with biofertilizers over the control. FYM+TR showed highest increase in nutrient uptake of N: 74.77 kg ha^{-1}, P: 35.16 kg ha^{-1} , and K : 43.88 kg ha^{-1}, Ca: 49.53 kg ha^{-1}, Mg: 26.29 kg ha^{-1}, Fe: 0.48 kg ha^{-1}, Mn 0.22 kg ha^{-1}, Cu 0.07 kg ha^{-1}, Zn 0.14 kg ha^{-1} compared to the negative control. Nutrient content in potato tubers was significantly higher than the one in the potato shoot. The nutrient results showed significant differences in all nutrients across the fertilizer treatments. The N, P, and K and micronutrients (Ca, Fe, Mn, Zn, Cu, and Mg) were affected by fertilizer treatments in potato tubers and shoot. Also, the combination of inorganic fertilizers (NPK) and biofertilizers increased significantly uptake compared to when NPK and biofertilizer are applied singly. Finally, results revealed that increased uptake was positively correlated to maximum tuber yield. The study recommends using integrated FYM and Biofertilizers for potato production in Kenya as they were found to increase nutrient uptake, which is beneficial to potato production.

Keywords : *Bacillus subtilis*, Biofertilizers, FYM, *Kenya mpya*, Nutrients uptake, *Shangi*, *Trichoderma asperellum*

1.0 Introduction

Potato (*Solanum tuberosum*), compared to cereal crops has a very high nutrient requirement but it's a heavy feeder. It responds well to fertilizer applications and produces high yield per unit area at a given time. Because fertilizer is an expensive input, Biofertilizers could supplement the nutrient requirements of the potato crop, particularly phosphorus, thereby increasing yield. Using organic manures with biofertilizers improves the soil's physical, chemical, and biological properties while increasing fertilizer use efficiency and crop yield (Kumar *et al*., 2012). Mineral fertilizer applications have adverse effects on our environment and animal health. As a result, any operation or method that attempts to reduce environmental pollution will positively impact our lives. Today, environmental protection is more critical for agrarians, especially when it comes to sustainable agriculture. In retrospect, Biofertilizers are less harmful to the environment than mineral fertilizers which offers a solution to curbing with increasing environmental pollution (Davod *et al*., 2011)

Beneficial microorganisms used as biofertilizers in sustainable agriculture practices have emerged as an innovative and environmentally friendly method of improving soil fertility and plant growth. The soil microbiome comprises of bacteria, fungi, algae, protozoa, archaea, and viruses. Nevertheless, beneficial bacteria and fungi are essential in improving crop productivity for sustainable agriculture improving soil properties, increasing nutrient availability, and producing plant growth hormones (Basu *et al*., 2021). Certain microorganisms increase uptake by mobilizing it from the environment to plants (Ghorbanian *et al.,* 2012). They also play essential roles in nutrient availability in soil and stress alleviation. Besides, microorganisms are essential components in the efficient functioning of soil ecosystems. They aid in increasing nutrient levels by influencing plant metabolism and thus changing the composition of root exudates. They also influence nutrient solubility and availability, and increasing interactions with other soil microbes (Fitter *et al.,* 2011). The microorganisms in biofertilizers use several mechanisms to benefit crop plants. They can be efficient phosphate solubilization and plant growth promotion or they can combine all these traits. They can also fix atmospheric nitrogen through the biological nitrogen fixation (BNF) process. In addition, they solubilize nutrients required by plants, zinc, Potassium, and secrete plant growth-promoting substances such as hormones (Kumar *et al*., 2018).

Organic and biofertilizers can help increase yield while reducing the harm caused by chemical fertilizers (El-Lithy *et al.,* 2014). Biodiversity, biological activity and biological cycles in soil are also enhanced, resulting in socially, ecologically, and economically sustainable natural systems. *Trichoderma* (fungal genus) is one of the microorganisms currently marketed as an active ingredient in biofertilizer, bio-fungicide, growth enhancer, and natural resistance stimulant. *Trichoderma* species were discovered to improve mineral uptake, nitrogen use efficiency, photosynthesis efficiency, and nutrient solubilization in soil and organic matter; and plant hormone production (Kapri and Tewari, 2010). Moreover, the introduction of *Trichoderma* strains with or without pathogens did not affect the existing soil beneficial populations. For these reasons, *Trichoderma* species are known as plant growth-promoting fungi or biofertilizers. On the other hand, farmyard manure has been used as a soil conditioner since ancient times. It supplies all macro as well as micronutrients necessary for plant growth and enhances crop production. Hence, it acts as a mixed fertilizer and improves the physical, chemical, and biological properties of soil (Khan *et al*., 2010). The incorporation of manures in the soil has a beneficial effect on soil health by improving physico-chemical properties besides supplying the macronutrients like nitrogen (Aghili *et al.*,2014: Dhaliwal & Walia 2008). Therefore, the present study was carried out to determine the response of potatoes to different combinations of organic manure and biofertilizers. There is limited information

regarding the effect of integrated nutrient management on soil physicochemical properties and nutrient uptake.

2. Materials and methods

2.1 Site description

The field experiment was conducted at Egerton University, main campus Njoro and KALRO Tigoni, Kiambu County in Kenya. Egerton University lies between longitude 35° 35' E, latitude 0° 23' S, and at an altitude of 200 meters above sea level (m asl). The temperature range is between 17-22°C, with an average annual rainfall of 1000 mm (Waithaka *et al*., 2019). KALRO, Tigoni is located in Kiambu County, on latitude 1'080 S and longitude 36'400 E. The area receives 1800 mm annually, and temperatures range from 10°C to 25°C. It has an altitude of 2100 m asl (Mbiyu *et al*., 2018).

2.2 Experimental procedure, design and germplasm

2.2.1 Germplasm

Shangi and *Kenya Mypa* varieties were used in this study. *Shangi* variety is the most grown variety in Nakuru. It is a semi-erect medium-tall variety with moderately strong stems. The leaves are broad with light green and pink flowers (Figure 1.1 A). It grows well at an altitude above 1500 m asl, such as Nakuru, Kericho, Bomet, and Narok. It has an early maturing variety with an average yield of 30-40 tons ha^{-1}. It has an oval-shaped tuber, smooth cream skin, medium to deep eyes, and white flesh (Figure 1.1 B) (National Potato Council of Kenya., 2019).

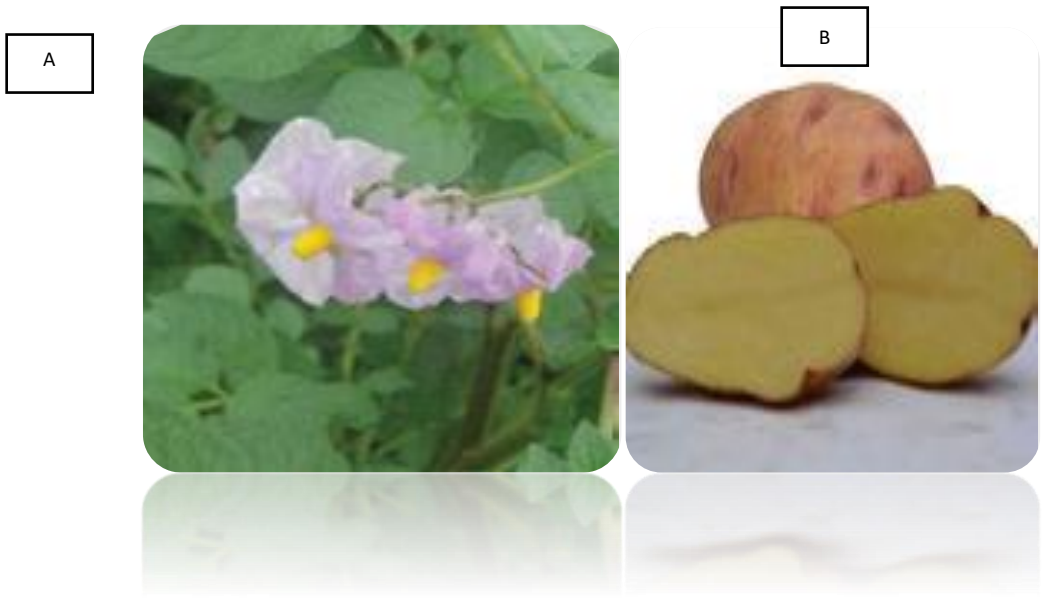

Figure 1*:* A: flowers of *Shangi* Variety and B: its tubers

2.2.2 Experimental Design and Procedure

Egerton site had done two seasons, while Tigoni site had one season as the second failed due to lockdown in 2020 between Nairobi and Kiambu counties due to COVID19 restrictions. The experiments were conducted at Egerton University in October 2019 and March 2020, while at KALRO, Tigoni, it was conducted in October 2019. Egerton season 1 (2019) was considered Environmental 1, Egerton season 2 (2020) considered Environmental 2, while Tigoni season 1 (2019) was considered Environmental 3.

Land preparation was done using a mouldboard plough, after which it was harrowed. Farmyard manure was applied at 30 tons ha^{-1} and incorporated in the soil for two weeks before planting

(Turamyenyirijuru, 2013). Certified potato seeds of *Shangi*, and *Kenya Mypa* varieties were sourced from KALRO – Tigoni Research Centre. Both were planted at a spacing of 75 cm × 30 cm with a planting depth of 10 cm. Biofertilizers (*Trichoderma asperellum* and *Bacillus subtilis*) were applied at 150 mL/10 kg of seed. The recommended dose of fertilizers (NPK 23: 23: 0) was applied at 300 kg ha^{-1} and 0 kg ha^{-1} as positive and negative controls, respectively. The field experiment was laid in a randomized complete block design split-plot arrangement. The plots were kept weed-free and earthing up and was done twice. At the same time, insects and diseases were controlled using Cypertox 250 Ec (cyhalothrin 25 gl^{-1}) and Ridomil gold (Metalaxyl-M 40 gkg-1+Mancozeb 640 gkg^{-1}), respectively. The varieties were the main plot, farmyard manure, and biofertilizer treatments as sub-plots and replicated three times. The experiment entailed of 10 treatment combinations comprising organic manures with and without biofertilizers (Table I). The rates for fertilizer treatments which have used were calculated according to farmers' practice and recommended nitrogen rate (90 kg ha^{-1}) (National Potato Council of Kenya., 2013: Nyongesa *et al.*, 2008).

Table 1: Treatment Combinations for the Experiment.

S.N.	Treatment	Treatment details
1	T_0	Negative control (0 NPK)
2	T_1	Positive control (=RDF = NPK 300 kg ha^{-1})
3	T_2	RDF + *Trichoderma asperellum*
4	T_3	RDF + *Bacillus subtilis*
5	T_4	*Trichoderma asperellum*
6	T_5	*Bacillus subtilis*
7	T_6	FYM
8	T_7	FYM + *Trichoderma asperellum*
9	T_8	FYM + *Bacillus subtilis*
10	T_9	*Trichoderma asperellum + Bacillus subtilis*

2.3 Data collection

The number of stems per plant and plant height was taken at 14, 21, 28, and 35 days after emergence (DAE). After harvesting, 10 plants from the middle rows were uprooted per plot, and a number of tubers counted. The average number of marketable tubers was evaluated and counted for those equal to or greater than 30 g and not attacked by disease and insects. The average number of unmarketable tubers was sorted as diseased, insect attack, and small-sized (<30 g). Tubers were then graded into three classes; big size: >60 mm diameter, medium size: 30-60 mm diameter- small size: <30 mm (Gebreselassie *et al.*, 2016).

2.4 Soil sampling and preparation

Before planting and after harvest of the experiment, soil samples were randomly collected from the experimental fields. Soil auger was used to get the soil in a zigzag pattern dug at 0-30 cm depth. Then composited soil samples (before planting and post-harvest) were sent to Kenya National Agricultural Research Laboratory (NARL) KALRO Kabete for selected physic-chemical analyses. Soil availability of nitrogen, phosphorus, potassium, calcium, magnesium, organic carbon, pH, and soil texture was analyzed. Total nitrogen was analysed by Kjeldahl method. Briefly, the samples were oven - dried at 400 °C, (< 0.5 mm) digested with concentrated sulphuric acid containing potassium sulfate, selenium, and copper sulfate hydrated at approximately 3500 °C. Total N was determined by distillation followed by titration with diluted standardized H_2SO_4 (Page *et al*., 1982). Total organic carbon was analysed by Calorimetric method. Samples were oven-dried at 400 °C (< 0.5 mm) then oxidized by acidified dichromate at 1500 °C for 30 minutes to ensure complete oxidation. The cool

digests were supplemented with barium chloride. Digests were allowed to stand overnight after thorough mixing. The carbon concentration was measured using a spectrophotometer at 600 nm (Anderson and Ingram, 1993). Soil pH was determined in a 1:1 (w/v) soil–water suspension with a pH–meter.

The trace elements (Fe, Zn & Cu) were extracted in 0.1 M HCl. The soil samples were oven-dried at 400 °C. They were then extracted in a 1:10 ratio (w/v) with 0.1 M HCl. Elements were then determined with AAS (Atomic Absorption Spectrophotometer). The available nutrient elements (P, K, Na, Ca, Mg and Mn) were determined by Mehlich Double Acid method. Soil samples were oven-dried at 400 °C, (< 2 mm), then extracted in a 1:5 ratio (w/v) with a mixture of 0.1 M HCl and 0.025 M H_2SO_4. Elements such as Na, Ca, and K were determined with a flame photometer and P, Mg, and Mn – spectrophotometrically (Mehlich *et al*., 1962).

2.5 Assessment of macronutrients and micronutrients uptake

At maturity, three plants from selected treatments indicated in (Table 1) were uprooted for nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Copper (Cu), and Manganese (Mn), Zinc (Zn), nutrients uptake analyses. Potato tuber samples of 50 g were dried in an oven at 70 °C for 72 h. The samples were labeled and taken to NARL-KARLO Nairobi for N, P, and K analyses using the methods described in (4.3.1). The nutrients uptake was calculated using the following formula:

$$\textbf{Nutrients Uptake}\ \text{kg ha}\ -1 = Nutrients\ \%\ X\ d.w \ldots\ldots\ldots\ldots\ldots\ldots (Equation\ 1)$$

Where: d.w= Dry weight Agronomic efficiency (or fertilizer use efficiency) was calculated using potato production excluding control over total input applied (Badr *et al*., 2012)

1.6 Data Analysis

The Shapiro-Wilk test was used to determine the normality of data collected on growth, yield, and quality parameters. Outliers in the data were identified and removed. The data were subjected to the SAS software version 9.2. Analysis of variance (ANOVA) and General Linear Model (GLM) procedures of SAS (9.3) at $P \leq 0.05$ was done (Statistical Analysis System (SAS) Institute., 2002).

3. RESULTS

3. 1 Effects of Biofertilizers and Farmyard Manure soil physico-chemical properties

Farmyard Manure (FYM) was collected at the two sites and samples analysed. Results revealed that Egerton site had highest Nitrogen (N) content , while Tigoni was highest in other nutrients, i.e., Phosphorus (P), Potassium (K), Calcium (Ca), Mangnisum (Mg), Irone (Fe), Copper (Cu), Manganese (Mn) and Zink (Zn) (Table 2).

Table 2: Nutrient content of FYM from the experimental sites.

Sample description	Egerton	Tigoni
Nitrogen (gkg^{-1})	0.58	0.47
Phosphorus (gkg^{-1})	0.36	0.61
Potassium (gkg^{-1})	1.16	2.14
Calcium ($cmolkg^{-1}$)	1.10	1.87
Magnesium ($cmolkg^{-1}$)	0.15	0.04
Iron ($cmolkg^{-1}$)	17454	51118
Copper ($cmolkg^{-1}$)	56.7	75.0
Manganese ($cmolkg^{-1}$)	1330	3433
Zinc ($cmolkg^{-1}$)	397	1697

Soil fertility in the two environments was significantly affected by fertilizer treatments; after harvesting, most nutrients showed an increase than before planting. After harvesting, the Phosphorus, Iron, and Calcium showed the highest increase than before planting, P (0.65-0.70), Fe (0.61 -0.66), and Ca (0.63- 0.68) Na (0.30-0.36) (Figure 2). At Tigoni showed the highest increase in soil fertility after harvesting than before planting for Nitrogen, Phosphorus, Potassium, and Organic carbon and micronutrient (Calcium, Iron, Zinc, Copper, Manganese, and Sodium) compared to Egerton site (Table 3)

Table 3: Soil physicochemical properties before planting and after harvesting potatoes in experimental sites

Parameters	Egerton1			Egerton2			Tigoni		
	Before Planting	After Harvesting	LSD	Before Planting	After Harvesting	LSD	Before Planting	After Harvesting	LSD
Soil pH.	6.70a	5.93a	2.60	6.60a	5.78a	4.19	4.50b	5.72a	0.19
Organic Carbon	2.92a	3.01a	1.52	2.67a	2.82a	1.97	2.60a	3.05a	0.76
Nitrogen %	0.24a	0.25a	0.13	0.65a	0.66a	0.64	0.26a	0.29a	0.25
Phosphorus%	0.65a	0.68a	38.12	0.65a	0.67a	37.55	0.65b	0.70a	95.30
Potassium%	1.45a	1.49a	1.97	1.49a	1.50a	4.00	0.89a	0.90a	1.27
Calcium%	0.45a	0.48a	9.91	0.37a	0.40a	16.01	0.63b	0.68a	1.59
Magnesium%	0.81b	0.85a	1.65	0.10a	0.13a	0.19	0.62a	0.63a	2.54
Iron mg/kg	0.47a	0.50a	5.08	0.50a	0.52a	4.45	0.61b	0.66a	19.06
Copper mg/kg	0.67a	0.70a	0.25	0.47a	0.51a	0.06	0.76b	0.79a	0.38
Manganese mg/kg	0.50a	0.55a	0.64	0.48a	0.50a	0.13	0.82a	0.85a	0.01
Zink mg/kg	0.40a	0.45a	3.18	0.30a	0.31a	6.45	0.60a	0.62a	6.35
Sodium mg/kg	0.12a	0.19a	0.38	0.14a	0.15a	0.35	0.30b	0.36a	0.06

Values are means; the means followed by the same letters are not significantly different in the same row according to the Least Significant Difference (LSD) test at a 5 % level of significance

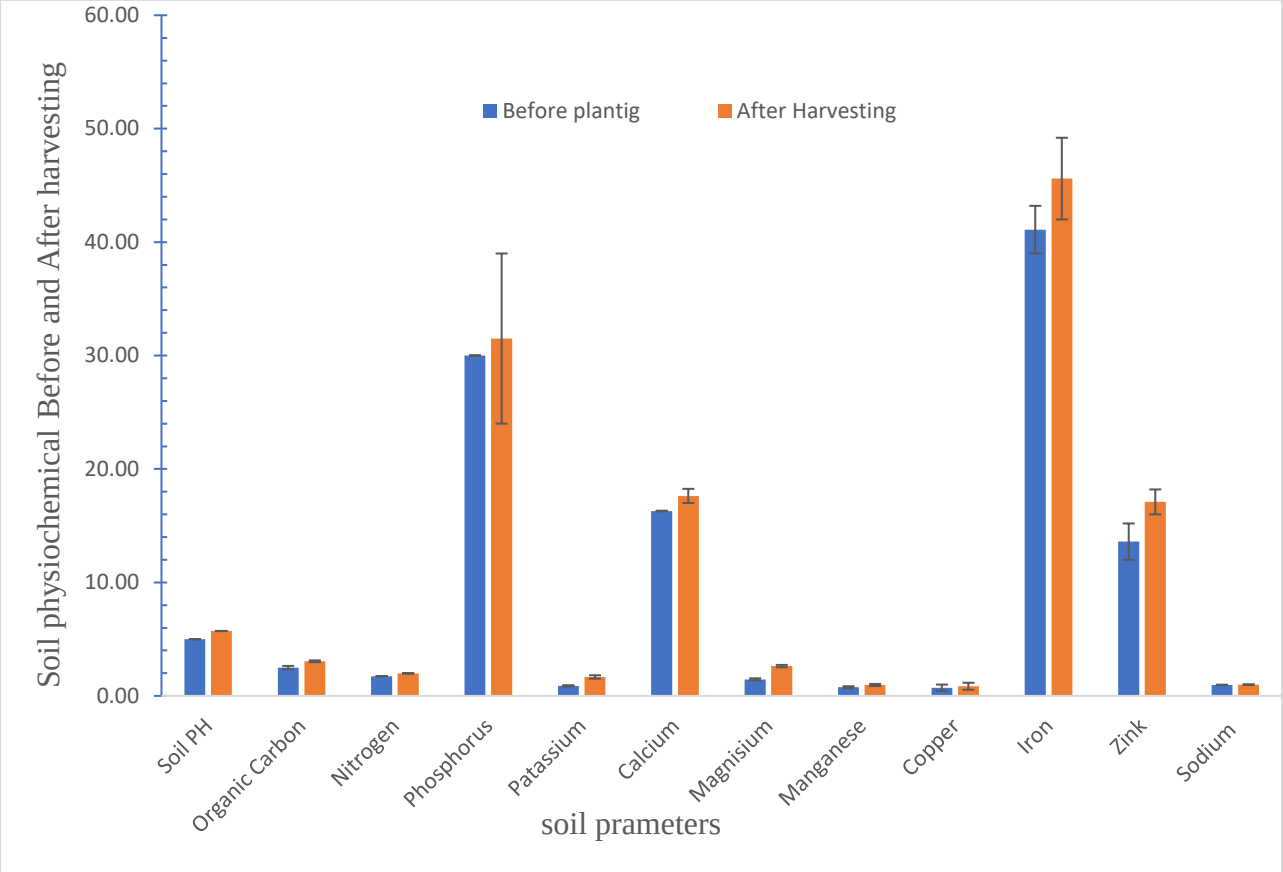

***Figure 2**: Soil physic-chemical properties before planting and after harvesting experimental sites (Egerton season 1, Egerton season 2, and Tigoni season1)*

3.2 Effects of Biofertilizers and Farmyard Manure Application on nutrients uptake of potato

Nutrient uptake was significantly affected by environments, fertilizers treatments, and variety ($p \leq 0.001$). Iron uptake was affected by environments, fertilizers treatments, and variety ($p \leq 0.05$). Tigoni had highest nutrients uptake in Nitrogen 51.43 t $ha^{-1,}$ Phosphorus 22.34 (kg ha^{-1}), Calcium 32.54 (kg ha^{-1}), Magnesium 17.81 (kg ha^{-1}), Iron 0.47 (kg ha^{-1}), Manganese 0.15 (kg ha^{-1}), Copper 0.05 (kg ha^{-1}), and Zinc 0.10 (kg ha^{-1}). Although Egerton 2 and Tigoni were not significantly different in Potassium uptake, Egerton 2 had the highest nutrient uptake for Potassium, 21.40 (kg ha^{-1}) (Figure 2)

The fertilizer treatments showed significant differences in all nutrient uptakes, T7: (FYM+ TA) showed the highest increase for all nutrient uptake. However, T7 and T8: FYM + *Bacillus subtilis* were not significantly different in Calcium, Manganese, iron, and Zinc. Varietal differences were observed on nutrient uptake; *Kenya mpya* had higher tuber nutrient uptake for Nitrogen 43.94 kg ha^{-1} while *Shangi* had highest copper and Magnesium uptake 14.18 kg ha^{-1} and 0.12 kg ha^{-1}, respectively, although was no a significant difference to *Kenya mpya* (Table 4).

Table 4: Effects of Biofertilizers and Farmyard Manure Application on nutrient uptake at Egerton and and Tigoni

Environments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kgha^{-1})	Copper (kg ha^{-1})	Zinc (kg ha^{-1})
Egerton 1	31.86 c	11.24b	31.91a	32.20b	11.44c	0.27b	0.10b	0.03b	0.04c
Egerton 2	36.45 b	19.45b	33.13a	38.42a	13.21b	0.25b	0.11b	0.03b	0.08b
Tigoni	51.43 a	22.34a	21.40b	32.54b	17.81a	0.47a	0.15a	0.05a	0.10a
LSD	1.89	0.07	1.36	2.51	0.05	0.02	0.02	0.02	0.01
Treatments									
T5	23.91g	10.36g	22.17e	27.49de	8.64f	0.25cd	0.09e	0.02f	0.05d
T6	33.84f	12.16f	29.596d	28.85de	11.02e	0.27cd	0.09de	0.02f	0.07c
T8	66.97b	33.92b	41.40b	46.35a	25.26b	0.46a	0.21a	0.06b	0.13a
T7	74.77a	35.16a	43.88a	49.53a	26.29a	0.48a	0.22a	0.07a	0.14a
T0	11.07h	4.88i	10.10g	21.57f	3.34h	0.16d	0.03f	0.01h	0.02e
T3	43.45d	23.12d	35.14c	39.87b	18.75c	0.36b	0.14c	0.04d	0.10b
T1	24.67g	8.20h	19.33f	24.55fe	7.05g	0.23cd	0.08e	0.02g	0.04d
T2	48.70c	25.11c	37.09c	40.00b	19.14c	0.46a	0.17b	0.05c	0.11b
T4	37.88f	13.72e	28.51d	33.89c	12.66d	0.30cb	0.12dc	0.03e	0.08c
T9	33.88e	10.14g	20.02fe	31.76dc	9.37f	0.35b	0.07e	0.02f	0.05d
LSD	3.46	1.23	2.48	4.58	1.02	0.10	0.03	0.01c	0.01
Varaties									
Kenya mpya	43.94a	22.61a	29.75a	35.56a	14.12a	0. 37a	0.11a	0.04a	0.08a
Shangi	35.88b	12.74b	27.88b	33.21b	14.18a	0. 29b	0.12a	0.03b	0.07a
LSD	1.55	0.55	1.11	2.05	0.46	0.04	0.01	0.01	0.01

Values are means; the means followed by the same letters are not significantly different according to Least Significant Difference (LSD) test at a 5 % level of significance. Key: T0: 0 Recommended dose of fertilizer (RDF) T1: RDF T2: RDF + *Trichoderma asperellum* T3: RDF + Bacillus subtilis T4: *Trichoderma asperellum* T5: *Bacillus subtilis* T6: FYM T7: FYM + *Trichoderma asperellum* T8: FYM + *Bacillus subtilis* T9: *Trichoderma asperellum + Bacillus subtilis*

In Egerton season one, all the treatments significantly influenced nutrient parameters (Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Manganese, Copper, Iron, and Zinc). *Kenya mpya* variety had highest nutrient uptake than *Shangi*. *Kenya mpya* had the highest nutrient uptake in plants treated with T7: FYM+*Trichoderma asperellum*. However, the highest P (31 (kg ha^{-1}), and Fe 0.39 ((kg ha^{-1}), was recorded with T8*:* FYM+ *Bacillus subtilis*, compared the negative control. *Shangi* variety had the highest nutrient uptake from plants treated with T7, compered the negative control (untreated plot) (Table 5)

In the same way, in Egerton season two, all the treatments significantly influenced nutrient parameters. The highest nutrient uptake was observed with plants treated with T7. In the varieties *Kenya mpya* variety had the highest nutrient uptake than *Shangi.* Both varieties recorded the highest nutrient uptake in the plots treated with T7 (Table 6).
Consistently in Tigoni all the treatments were significantly influenced by nutrient uptake. *Kenya mpya* variety had highest nutrient uptake than *Shangi* (Table 7)

Table 5: Effect of farmyard manure and biofertilizer treatments on nutrient uptake of *Shangi* and *Kenya mypa* (Egerton 1)

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kg ha^{-1})	Copper(kg ha^{-1})	Zinc (kg ha^{-1})
KENYA MPYA									
T5	16.61e	3.12 ef	12.71 ef	30.50 d	5.04 f	0.15 f	0.05a	0.07 d	0.02g
T6	38.02 cd	5.61 d	40.94 a	42.29 b	14.95 c	0.30 b	0.02 bc	0.11 b	0.05 cd
T8	47.56b	31.35 a	32.67 ab	54.69 a	25.36 b	0.39 a	0.05 a	0.14 a	0.06 ab
T7	63.98 a	31.25 a	36.76 a	60.64 a	26.67 a	0.38 a	0.03 ab	0.15 a	0.07a
T0	34.25d	20.68 c	19.43 cde	44.22 b	13.35 d	0.26 c	0.02 bc	0.11 b	0.05 bcd
T3	11.36 e	1.40 f	8.68 f	14.42 e	2.73 g	0.13 f	0.01 c	0.05 e	0.02 g
T1	18.01e	2.53ef	13.96 ef	33.27 cd	5.23 f	0.18 e	0.03 ab	0.11 c	0.03 f
T2	41.99 bc	24.64 b	23.87 bcd	43.54 b	13.64 cd	0.30 b	0.02 bc	0.11 c	0.06 ab
T4	35.68 cd	5.67d	26.48 bc	39.08 bc	9.53 e	0.25 cd	0.05 a	0.13a	0.05 cd
T9	31.75 d	4.14 de	16.64 def	31.75 cd	5.26 f	0.23 d	0.02 bc	0.06 de	0.05 d
LSD	6.97	2.06	9.08	8.53	1.53	0.03	0.03	0.02	0.01
SHANGI									
T5	12.12 ef	4.98 e	16.21 cd	32.93 cd	7.01 f	0.20 b	0.03 cd	0.09 d	0.03 bcd
T6	36.47 c	12.39 c	9.76 ef	36.34 abc	10.13 d	0.22 b	0.05 b	0.09 d	0.08 a
T8	55.94 ab	17.47 a	37.42 ab	7.68e	21.38 a	0.35 ab	0.02 cde	0.17 b	0.03 cd
T7	60.68 a	18.43 a	38.99 a	8.88 e	20.50 a	0.32 ab	0.01 f	0.19 a	0.02 d
T0	28.19 cd	12.47 c	34.38 b	41.36 a	12.01 c	0.24 b	0.03 c	0.08 de	0.06 abc
T3	8.585 f	2.208 g	7.968 f	9.713 e	3.137 h	0.151 b	0.01 f	0.06 f	0.02 d
T1	11.151 f	3.633 f	12.804 de	28.911 d	4.623 g	0.156 b	0.018 de	0.074 e	0.03 cd
T2	46.53 b	14.04 b	34.39 b	39.83 ab	14.32 b	0.82 a	0.08 a	0.12 c	0.07 ab
T4	16.36 ef	7.01 d	17.05 c	35.25 bc	9.09 de	0.24 b	0.05 b	0.12 c	0.05 abcd
T9	11.75 ef	4.14 e	16.64 cd	31.75 cd	5.26 f	0.23 b	0.02 cd	0.06 de	0.05 abcd
LSD	9.8	1.28	4.25	5.32	1.37	0.53	0.01	0.02	0.04

Values are means; the means followed by the same letters are not significantly different according to Least Significant Difference (LSD) test at a 5 % level of significance

Table 6: Effect of farmyard manure and biofertilizer treatments on nutrient uptake of *Shangi* and *Kenya mypa* (Egerton 2)

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kg ha^{-1})	Copper (kg ha^{-1})	Zinc (kg ha^{-1})
KENYA MPYA									
T5	23.49 de	12.35 d	36.54 b	31.67 d	8.68 ef	0.16 ef	0.02 de	0.12 e	0.05 d
T6	22.69 de	11.47 d	21.79 d	25.82 de	8.87 e	0.18 ef	0.02 de	0.13 e	0.05 d
T8	66.86 a	47.93 a	48.98 a	67.07 a	33.50 ab	0.56 a	0.08 a	0.38 a	0.24 a
T7	75.63 a	46.15 a	53.25 a	71.17 a	36.03 a	0.57 a	0.09 a	0.39 a	0.25 a
T0	50.45 b	28.99 b	48.95 a	54.22 b	29.66 bc	0.38 bc	0.04 bc	0.20 b	0.20 b
T3	12.38 e	5.26 e	11.87 e	19.72 e	4.64 f	0.08 f	0.09 e	0.03 f	0.02 e
T1	20.20 e	8.32 de	25.36 cd	26.03 de	7.86 ef	0.27 cde	0.01 de	0.14 de	0.05 d
T2	43.29 bc	24.51 b	41.31 b	47.80 bc	26.85 c	0.32 bcd	0.04 b	0.18 bc	0.18 b
T4	32.31 cd	18.27 c	38.71 b	42.93 c	16.26 d	0.21 def	0.03 cd	0.16 cd	0.11 c
T9	44.81 b	10.15 de	28.56 c	47.98 bc	9.70 e	0.45 ab	0.02 cd	0.10 e	0.03 de
LSD0.05	11.61	5.07	6.67	9.42	4.19	0.14	0.01	0.04	0.03
SHANGI									
T5	20.92 ef	12.11 de	20.17 f	27.85 c	7.08 e	0.13 e	0.01 d	0.04 de	0.05 d
T6	20.72 ef	11.28 ef	20.19 f	24.99 cd	4.79 f	0.16 de	0.01 d	0.03 ef	0.04 d
T8	58.24 b	28.02 b	52.07 b	53.81 a	14.15 b	0.28 ab	0.03 c	0.07 b	0.09 b
T7	68.74 a	34.39 a	58.46 a	53.65 a	17.27 a	0.30 a	0.06 a	0.10 a	0.11 a
T0	31.98 d	20.07 c	28.97 d	34.49 b	9.11 d	0.22 bc	0.03 bc	0.05 c	0.06 c
T3	13.48 f	5.93 g	12.06 g	21.11 d	2.34 g	0.11 e	0.07 d	0.09 h	0.02 e
T1	20.43 ef	9.35 f	22.72 ef	25.83 cd	5.29 f	0.14 de	0.01 d	0.04 e	0.04 d
T2	49.11 c	21.22 c	34.76 c	35.27 b	10.14 c	0.20 cd	0.03 b	0.04 cd	0.06 c
T4	26.413 de	19.203 c	27.00 de	30.61 bc	7.20 e	0.19 cd	0.01 d	0.09 fg	0.05 d
T9	26.94 de	14.00 d	30.91 cd	26.41 cd	4.74 f	0.11 e	0.01 d	0.02 g	0.01 e
LSD0.05	7.70	2.04	4.72	6.28	0.89	0.06	0.01	0.01	0.01

Values are means; the means followed by the same letters are not significantly different according to Least Significant Difference (LSD) test at a 5 % level of significance

Table 7: Effect of farmyard manure and biofertilizer treatments on nutrient uptake of *Shangi* and *Kenya mypa* (Tigoni)

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kg ha^{-1})	Copper (kg ha^{-1})	Zinc (kg ha^{-1})
KENYA MPYA									
T5	35.24 de	21.84 de	22.46 de	13.86 fgh	7.47 e	0.22 ef	0.01 fg	0.07 c	0.02 def
T6	43.65 cd	25.24 d	28.08 cd	16.67 efg	9.42 d	0.26 e	0.02 ef	0.03 e	0.027 de
T8	118.39 a	56.43 ab	46.88 a	49.40 a	25.65 a	0.52 a	0.19 a	0.24 a	0.22 a
T7	125.86 a	59.97 a	50.93 a	39.28 ab	24.60 b	0.46 b	0.11 b	0.20 b	0.20 b
T0	66.39 b	44.54 c	39.08 b	28.83 cd	17.44 c	0.34 d	0.06 c	0.06 d	0.07 c
T3	15.36 g	11.17 f	10.77 f	5.51 h	1.34 g	0.13 g	0.01 h	0.02 e	0.01 f
T1	33.92 ef	19.83 e	17.15 e	7.99 gh	4.97 f	0.20 f	0.02 gh	0.05 d	0.02 ef
T2	72.69 b	52.01 b	40.71 b	32.47 bc	19.17 c	0.38 cd	0.06 c	0.08 c	0.08 c
T4	49.74 c	25.11 d	28.66 c	20.26 def	9.36 d	0.25 e	0.02 e	0.03 e	0.04 d
T9	25.72 f	21.57 de	20.29 e	26.88 cde	7.53 e	0.41 bc	0.05 d	0.03 e	0.04 d
LSD	9.14	4.61	5.63	10.46	1.75	0.04	0.01	0.01	0.02
SHANGI									
T5	39.57 cd	7.77 d	24.92 e	28.13 cd	16.53 e	0.63 abc	0.03 d	0.14 cde	0.12 d
T6	41.73 cd	6.99 de	27.58 de	27.00 cd	17.98 de	0.53 abc	0.03 d	0.16 cde	0.14 cd
T8	63.96 a	23.39 a	54.37 a	55.45 ab	35.65 a	0.79 a	0.11 b	0.38 ab	0.23 a
T7	64.22 a	22.77 a	54.13 a	58.93 a	35.70 a	0.80 a	0.12 a	0.39 ab	0.22 ab
T0	54.50 b	11.96 c	40.03 bc	56.56 ab	30.95 b	0.69 ab	0.05 c	0.31 abc	0.17 bcd
T3	5.23 e	3.29 f	14.62 f	23.10 d	5.89 f	0.36 c	0.01 e	0.05 e	0.02 e
T1	39.768 cd	5.545 e	24.001 e	25.228 d	14.345 e	0.465 bc	0.02 e	0.09 de	0.06 e
T2	55.72 b	14.23 b	44.512 b	36.09 bcd	30.71 b	0.73 ab	0.06 c	0.49 a	0.19 abc
T4	42.53 c	7.04 de	33.159 cd	35.27 bcd	24.49 c	0.64 abc	0.04 d	0.24 bcd	0.16 bcd
T9	34.35 d	6.17 de	15.834 f	48.79 abc	21.16 cd	0.72 ab	0.03 d	0.11 de	0.12 d
LSD	7.81	2.09	7.08	22.58	4.10	0.29	0.01	0.18	0.05

Values are means; the means followed by the same letters are not significantly different according to the Least Significant Difference (LSD) test at a 5 % level of significance

3.3 Correlation between nutrient uptake and yield parameters for *Shangi* and *Kenya mpya* evaluated in Egerton 1, Egerton 2 and Tigoni

The nutrient uptake (Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Iron, manganese, Copper, and Zinc) was strongly correlated with yield parameters. All nutrients showed a significant positive correlation between them. However, there was no correlation between Zinc and P, and K (Table 8).

3.4 Effects of Biofertilizer and Farmyard Manure Application on Potato leaf and tuber nutrients uptake (Egerton season 2)

Nutrient uptake was significantly affected by plant parts, fertilizers treatments, and variety ($p \leq 0.001$). Potassium and calcium were significantly affected by plant parts, fertilizers treatments, and variety ($p < 0.01$) (Appendix 4). The data on N, P, and K and micronutrients (Ca, Fe, Mn, Zn, Cu, and Mg) in potato tubers and the shoot was influenced by different fertilizer treatments. Nutrient content in potato tubers was significantly higher than the one in the potato shoot. The nutrient results showed significant differences in all nutrients across the fertilizer treatments. The N, P, and K and micronutrients (Ca, Fe, Mn, Zn, Cu, and Mg) were affected by fertilizer treatments in potato tubers and shoot (Table 2.8). T7: FYM + TA treatment had significantly higher for potato tubers and leaf as compared negative control, however, in some nutrients was not significant with T8 (FYM + BA). Varietal differences were observed in nutrient uptake where *Shangi* variety had higher nutrient uptake than *Kenya mpya* (Table 9).

Table 8: Pearson correlation coefficients (p-values) of nutrient uptake and yield for field experiment (combined for two sites)

Traits	N	P	K	Ca	Mg	Fe	Cu	Mn	Zn	Yield
P	0.85***									
K	0.72***	0.68***								
Ca	0.50***	0.40***	0.58***							
Mg	0.73***	0.56***	0.74***	0.71***						
Fe	0.56***	0.28*	0.53***	0.49***	0.79***					
Mn	0.76***	0.58***	0.55***	0.62***	0.76***	0.64***				
Cu	0.53***	0.33***	0.57***	0.63***	0.87***	0.71***	0.64***			
Zn	0.45***	0.24	0.18	0.54***	0.56***	0.38**	0.72***	0.45***		
Yield	0.40***	0.30**	0.45***	0.58***	0.49***	0.30**	0.55***	0.41***	0.50***	

Key: N : Nitrogen, P : Phosphorus , K: Potassium, Ca : Calcium Mg : Magnesium, Fe : Iron , Mn : Manganese , Cu: Copper , Zn : Zinc

Table 9: Effect of farmyard manure and biofertilizer treatments on nutrient uptake for tuber and leaf (Egerton 2)

Plant Parties	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kg ha^{-1})	Copper (kg ha^{-1})	Zinc (kg ha^{-1})
Tuber	34.70a	18.46a	31.66a	36.78a	12.52a	0.28a	0.10a	0.03a	0.08a
Laaf	24.47b	7.02b	25.33b	28.33b	2.54b	0.23b	0.09b	0.01b	0.02b
LSD	1.49	0.79	1.31	1.44	0.64	0.02	0.01	0.01	0.01
Treatments v									
T5	22.51f	8.90d	25.18e	27.09d	5.00de	0.21de	0.02e	0.08fe	0.04e
T6	21.62gf	7.18d	19.16f	23.52e	4.18e	0.22de	0.02e	0.08fe	0.04e
T8	42.13b	24.53a	42.83b	49.83a	12.81a	0.40b	0.04b	0.13b	0.10b
T7	49.18a	25.82a	46.80a	52.99a	14.11a	0.44a	0.06a	0.15a	0.11a
T0	30.00d	15.03b	32.18c	34.00b	9.72b	0.25dc	0.02d	0.10c	0.07c
T3	12.16h	3.52f	10.77g	15.60f	2.27f	0.11f	0.01g	0.05g	0.02g
T1	18.87g	5.40e	18.35f	21.45b	3.82e	0.19e	0.01f	0.07f	0.03fe
T2	33.43c	16.52b	34.80c	36.02c	10.49b	0.26c	0.03c	0.11c	0.07c
T4	26.62e	12.18c	28.74d	31.56c	7.06c	0.26c	0.02e	0.09d	0.05d
T9	29.35e	8.36d	26.18d	33.53cb	5.90dc	0.27c	0.02d	0.08e	0.03f
LSD	3.34	1.76	2.92	3.21	1.42	0.04	0.02	0.01	0.2
Varieties									
Shangi	31.30a	13.33a	32.78a	35.46a	9.89a	0.27a	0.13a	0.03a	0.07a
Kenya mpya	27.87b	12.16b	24.22b	29.66b	5.18b	0.25b	0.06b	0.02b	0.04b
LSD	1.49	0.79	1.31	1.44	0.64	0.02	0.01	0.01	0.01

Values are means; the means followed by the same letters are not significantly different according to Least Significant Difference (LSD) test at a 5 % level of significance

Nutrient uptake at Egerton 2 was affected by all fertilizer treatments. In both potato tubers and shoots. *Kenya mpya* variety had the highest nutrient uptake (N, P, and K). In potato tubers than Shangi. For both varieties, the highest nutrient uptake (N, P, and K) were obtained from plants treated with T7 (FYM + TA) compared to the negative control (Table 10). However in *Kenya mpya* the highest uptake for Ca 77.07 kg ha^{-1}, Mg 36.50 kg ha^{-1}, Mn 0.10 kgha^{-1}, Fe 0.56 kg ha^{-1}, Cu 0.38 kg ha^{-1}, and Zn 0.24 kg ha^{-1}, was obtained with the plants treated with T8 (FYM + BA) (Table 10)

For potato shoot, *Kenya mpya* variety had higher nutrient recovered than *Shangi*. The plant treated with T7 had highest uptake for all nutrients, across the two varieties compared to the negative control (Table 11)

Table 10: Effect of farmyard manure and biofertilizer treatments on nutrient uptake of *Shangi* and *Kenya mypa* for potato tubers. (Egerton 2)

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kg ha^{-1})	Copper (kg ha^{-1})	Zinc (kg ha^{-1})
KENYA MPYA									
T5	23.49 de	12.35 d	36.54 b	31.67 d	8.68 ef	0.16 ef	0.02 de	0.12 e	0.05 d
T6	22.69 de	11.47 d	21.79 d	25.82 de	8.87 e	0.18 ef	0.02 de	0.13 e	0.05 d
T8	66.86 a	47.93 a	48.98 a	77.07 a	36.50 a	0.56 a	0.10 a	0.38 a	0.24 a
T7	75.63 a	46.15 a	53.25 a	71.17 a	36.03 a	0.54 a	0.09 a	0.34 a	0.23 a
T0	50.45 b	28.99 b	48.95 a	54.22 b	29.66 bc	0.38 bc	0.04 bc	0.20 b	0.20 b
T3	12.38 e	5.26 e	11.87 e	19.72 e	4.64 f	0.08 f	0.09 e	0.03 f	0.02 e
T1	20.20 e	8.32 de	25.36 cd	26.03 de	7.86 ef	0.27 cde	0.01 de	0.14 de	0.05 d
T2	43.29 bc	24.51 b	41.31 b	47.80 bc	26.85 c	0.32 bcd	0.04 b	0.18 bc	0.18 b
T4	32.31 cd	18.27 c	38.71 b	42.93 c	16.26 d	0.21 def	0.03 cd	0.16 cd	0.11 c
T9	44.81 b	10.15 de	28.56 c	47.98 bc	9.70 e	0.45 ab	0.02 cd	0.10 e	0.03 de
LSD	11.61	5.07	6.67	9.42	4.19	0.14	0.01	0.04	0.03
SHANGI									
T5	20.92 ef	12.11 de	20.17 f	27.85 c	7.08 e	0.13 e	0.01 d	0.04 de	0.05 d
T6	20.72 ef	11.28 ef	20.19 f	24.99 cd	4.79 f	0.16 de	0.01 d	0.03 ef	0.04 d
T8	58.24 b	28.02 b	52.07 b	53.81 a	14.15 b	0.28 ab	0.03 c	0.07 b	0.09 b
T7	68.74 a	34.39 a	58.46 a	53.95 a	17.27 a	0.30 a	0.06 a	0.10 a	0.11 a
T0	31.98 d	20.07 c	28.97 d	34.49 b	9.11 d	0.22 bc	0.03 bc	0.05 c	0.06 c
T3	13.48 f	5.93 g	12.06 g	21.11 d	2.34 g	0.11 e	0.07 d	0.09 h	0.02 e
T1	20.43 ef	9.35 f	22.72 ef	25.83 cd	5.29 f	0.14 de	0.01 d	0.04 e	0.04 d
T2	49.11 c	21.22 c	34.76 c	35.27 b	10.14 c	0.20 cd	0.03 b	0.04 cd	0.06 c
T4	26.413 de	19.203 c	27.00 de	30.61 bc	7.20 e	0.19 cd	0.01 d	0.09 fg	0.05 d
T9	26.94 de	14.00 d	30.91 cd	26.41 cd	4.74 f	0.11 e	0.01 d	0.02 g	0.01 e
LSD	7.70	2.04	4.72	6.28	0.89	0.06	0.01	0.01	0.01

Values are means; the means followed by the same letters are not significantly different according to Least Significant Difference (LSD) test at a 5 % level of significance

Table 11: Effect of farmyard manure and biofertilizer treatments on nutrient uptake of *Shangi* and *Kenya mypa* for potato shoot (Egerton 2)

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Calcium (kg ha^{-1})	Magnesium (kg ha^{-1})	Iron (kg ha^{-1})	Manganese (kg ha^{-1})	Copper(kg ha^{-1})	Zink (kgha-1)
KENYA MPYA									
T5	22.90 c	4.943 de	28.73 e	24.85 def	1.43 b	0.21 c	0.01 ef	0.09 de	0.02 d
T6	21.91 c	3.590 efg	23.50 f	22.62 ef	1.30 b	0.21 c	0.01 fg	0.09 de	0.03 c
T8	31.09 b	11.535 b	48.04 b	41.88 b	3.67 ab	0.34 b	0.05 b	0.12 b	0.04 b
T7	40.51 a	15.923 a	51.19 a	55.26 a	6.52 a	0.46 a	0.06 a	0.19 a	0.05 a
T0	25.13 c	6.280 cd	35.09 d	28.62 cde	2.42 ab	0.21 c	0.01 d	0.09 de	0.02 d
T3	12.52 e	1.227 g	11.86 h	9.41 g	0.15 b	0.09 d	0.01 h	0.04 f	0.01 e
T1	17.88 d	2.493 fg	16.61 g	17.51 f	0.56 b	0.16 cd	0.01 gh	0.08 e	0.02 d
T2	30.27 b	8.170 c	37.43 c	30.91 cd	2.41 ab	0.24 c	0.02 c	0.10 cd	0.02 d
T4	23.21 c	4.727 def	30.42 e	25.12 de	2.30 ab	0.23 c	0.01 de	0.09 e	0.02 d
T9	25.27 c	4.623 def	29.58 e	35.21 bc	2.0 ab	0.22 c	0.01 f	0.08 bc	0.0 c
LSD	3.79	2.42	2.03	7.41	4.94	0.08	0.01	0.02	0.01
SHANGI									
T5	22.357 de	5.890 cd	14.377 g	23.370 cd	2.597 cd	0.315 cd	0.035 b	0.053 e	0.029 cd
T6	23.677 de	3.727 d	13.683 g	23.163 cd	2.560 cd	0.341 c	0.034 b	0.055 e	0.031 c
T8	31.190 ab	16.607 a	31.590 b	47.177 a	3.327 ab	0.460 b	0.024 cd	0.149 b	0.033 c
T7	34.827 a	16.723 a	33.673 a	43.753 a	3.590 a	0.520 a	0.046 a	0.171 a	0.059 a
T0	25.643 cd	9.517 bc	23.637 d	27.507 bc	2.363 de	0.233 e	0.026 cd	0.102 c	0.024 de
T3	9.200 g	1.213 d	6.127 i	10.337 e	1.633 f	0.145 f	0.010 e	0.008 g	0.010 f
T1	17.530 f	1.653 d	9.317 h	17.203 d	1.957 ef	0.209 e	0.025 cd	0.028 f	0.022 e
T2	28.770 bc	12.243 ab	25.820 c	30.300 b	2.887 bc	0.282 d	0.022 d	0.104 c	0.028 cd
T4	24.644 cde	6.511 cd	19.074 e	27.762 bc	2.511 cd	0.417 b	0.026 c	0.084 d	0.026 de
T9	20.973 ef	5.283 cd	16.917 f	24.703 bc	2.620 cd	0.310 cd	0.049 a	0.083 d	0.047 b
LSD	4.29	5.35	1.33	6.63	0.49	0.05	0.01	0.01	0.01

Values are means; the means followed by the same letters are not significantly different according to Least Significant Difference (LSD) test at a 5 % level of significance

3.5 Pearson correlation coefficients (p-values) of nutrient uptake of potato tuber and shoot

The nutrient uptake (Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Iron, manganese, Copper, and Zinc) of potato tuber was strongly positively correlated with nutrient uptake of potato shoot. Additionally, K was not significantly correlated with Cu (r=0.37) and Zn (r=0.41) in potato shoot (Table 12).

Table 12: Pearson correlation coefficients (p-values) of nutrient uptake for potato tuber and shoot at, Egerton 2

Nutrients	Plant Parts	N	P	K	Ca	Mg	Fe	Cu	Mn
P	Shoot	0.89***							
	Tuber	0.81***							
K	Shoot	0.86***	0.73***						
	Tuber	0.80***	0.87***						
Ca	Shoot	0.95***	0.91***	0.85***					
	Tuber	0.82***	0.92***	0.89***					
Mg	Shoot	0.6186**	0.51*	0.52**	0.71***				
	Tuber	0.73***	0.89***	0.79***	0.91***				
Fe	Shoot	0.78***	0.79***	0.47*	0.80***	0.52**			
	Tuber	0.72***	0.80***	0.70***	0.91***	0.85***			
Cu	Shoot	0.59**	0.57**	0.37	0.59**	0.44*	0.75***		
	Tuber	0.76***	0.95***	0.80***	0.92***	0.92***	0.84***		
Mn	Shoot	0.92***	0.85***	0.85***	0.93***	0.58**	0.69***	0.43*	
	Tuber	0.62**	0.77***	0.63**	0.80***	0.91***	0.85***	0.87***	
Zn	Shoot	0.64**	0.59**	0.41	0.65**	0.53**	0.79***	0.80***	0.63***
	Tuber	0.67***	0.89***	0.77***	0.88***	0.99***	0.81***	0.91***	0.90***

Key: N : Nitrogen, P : Phosphorus , K: Potassium, Ca : Calcium Mg : Magnesium, Fe : Iron , Mn : Manganese , Cu: Copper , Zn : Zinc

4. Discussion

Physico-chemical properties of soil for all experimental sites after harvest had shown an increase compared to before being planted. The result was in agreement with Bhuvaneshwari and Kumar (2013), who reported that N fertilizer and organic fertilizers (manure and Azolla biofertilizer) had effect on soil pH, N, P, and K. The report further claimed the fact that chicken manure can increase soil pH. Basically, soil pH was not the limiting factor for potato growth; however, fertilizer treatment's effect on soil pH only decreased in two sites while it showed an increase for other sites. This shows that fertilizer treatments have affected soil fertility. Other studies revealed that the application of organic fertilizers in the soil as soil amendments affected the soil pH (Havlin, 2014). FYM application led to higher soil Zn availability and increased Zn accumulation in wheat grains after applying red clover and green sunflower manure (G.M.) to the soil (Dhaliwal *et al.,* 2019). *Bacillus megaterium*, has been shown to improve mineral phosphorus (P) solubilisation. The proposed mechanisms for P- solubilization are the release of organic and inorganic acids, the excretion of protons associated with $NH4^+$ assimilation, and the release of phosphatase enzymes that mineralize organic P compounds . It also has the ability to dissolve Zn, K, Fe, and Mn . It also promotes root proliferation by releasing growth-promoting hormones. It provides P to plants at a rate of 10 to 15 kg/ha, saving up to 50% over the cost of P chemical fertilizer inputs. This biofertilizer can be used in seed treatment, root dipping for transplanting, soil application, and drip systems. *Pseudomonas, erwinia* and *P. chlororaphis* were able to strongly solubilize P sources, and HPCL analyses revealed the presence of several organic acids (Amalraj *et al.,* 2012). Bio-bacterial and bio-fungal fertilizers combining with organic fertilizers had .the highest increase providing the soil micronutrients (Zn, Fe, Cu, N, P, and K) (Altomare, *et al.*, 1999).

The result also revealed that application of different treatments had increased nutrient uptake. However, the application of the mixture of FYM and Biofertilizer had shown the highest uptake. Micronutrients when compared to macronutrients play an essential role in grain quality and yield of various crops, despite their requirement being significantly less than that of macronutrients. Also, the availability or forms (chemical pools) of macronutrients in soil, which are controlled by pH, E.C., O.C., and other soil properties, influence crop uptake in different cropping systems. Organic soil amendments have been linked to desirable soil properties ability to foster beneficial microorganisms (Mahmood *et al*., 2017). Choudhary *et al*., (2010) observed that application of biofertilizers - PSB and Azotobactor alone or in combination with organic fertilizers such as compost also resulted in improvement in the available N, P and K as well as micronutrient status to some extent such as Fe, Mn and Cu, the highest magnitude found at 30 t ha^{-1} by vermi-compost along with PSB or Azotobactor.

The nutrient uptake of different parts of potato was effected by the treatment applications. The combination of FYM and Biofertilizers showed the highest uptake especially for the tuber part. Sandhu *et al*., (2014) reported that NPK uptake by leaves stems and tubers increased significantly with increase in their rates of applications. Among the fertilizer treatments, application of organic fertilizers and biofertilizer had the highest NPK uptake in both years. This could be due to increase in availability of nutrients in the soil. The nutrient uptake by tubers was found closely linked with productivity and their higher concentration in plant.

Overall, macronutrient and micronutrient concentrations (N, P, and K) in potato tuber in all sites were high in the manure treatment with combination biofertilizer treatment. The results are similar

with Zeid *et al.,* (2015) who also found that chicken manure with biofertilizers was more effective at nutrient concentrations in radish leaves and tubers compared to other fertilizers and control. Bandopaddhya (2015) also reported that FYM at 30 t/ha along with biofertilizers recorded maximum soil fertility build-up after harvest of the crop. Biofertilizers treatments did exert significant effect on available N, P and K status of the soil under the study

5. Conclusion

Integrating organic fertilizers and biofertilizers could play a significant role in replenishing the depleted nutrients and sustaining the production and productivity of potato crops in Kenya. The results showed that applying FYM with biofertilizers (*Trichoderma asperellum*) had the highest macronutrient and micronutrient uptake in contrast to the control and other treatments. There was no were no significant difference in the performance of FYM + TA and FYM + BA in some micronutrients (Calcium, Manganese, iron, and Zinc). Amending the soil with cattle manure and biofertilizer raises soil organic matter and enhances the microbial, increasing the soil pH. This leads to more significant activities of soil microbes, improving soil nutrient availability. The beneficial bacteria and fungi are essential in improving crop productivity for sustainable agriculture improving soil properties, increasing nutrient availability and uptake, and producing plant growth hormones.

Declarations

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Effects of Selected Herbicides for Management of Weeds in Finger Millet (Eleusine Coracana L.) in Baringo and Kericho Counties

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Abstract

Finger millet (*Eleusine coracana* L.) production is limited by many factors and one of them is weed infestation. Efforts to manage weeds have seen farmers rely on manual weeding which has led to high drudgery among women. Use of herbicides provides an alternative to mechanical weeding hence realization of conservation agriculture. The objectives of this study were (i) to determine the effects of selected herbicides on weed control and yield of finger millet (ii) to determine the effects of different application rates of the herbicides at different growth stages on weed control and yield of finger millet. Field experiments were conducted in Baringo and Kericho Counties (Agricultural Training Centres) in 2020 and 2021 to determine the effects of selected herbicides on weed management. Herbicides evaluated included two post-emergent herbicides **(Ariane and 2-4D) and four pre-emergent herbicides (Sencor, Primagram, Maguguma and Dual gold).** The effectiveness of different rates of the best selected herbicides from locational trial was conducted at Njoro. Data was collected on %WCE, crop biomass, yields and crop phytotoxicity rating that was scored using a scale. The treatments mean for the experiment was separated using Tukey's honest significant difference at $p \leq 0.05$. The results of the study showed that post -emergent herbicides, **Ariane and 2-4D recorded higher weed control efficiency of 90.56% and 88.88% respectively and no phytotoxicity. Pre-emergent herbicides Sencor, Maguguma and Primagram recorded high weed control efficiency of** 89.92%, 90.13% and 88.34% respectively **however, they were associated with high crop phytotoxicity ratings, lower yields and crop biomass. 2-4D and Ariane recorded a higher crop biomass of 2.6 t/ha and 2.7 t/ha that as compared to negative control (no spray) that had a crop biomass of 0.5 t/ha. Application of 2-4D or Ariane resulted to higher yields of 5.04 t/ha and 5.4 t/ha respectively as compared to no yield when Lumax was used, Due to death of the crop due to phytotoxicity. Results from application of different rates of herbicides at different growth stage showed that application** of either 2-4D or Ariane at 1.5 times the registered rate of application during the seedling stage of the crop recorded a yield of 2.88 t/ha and 2.90 t/ha respectively with no crop phytotoxicity recorded. Findings of this study have demonstrated that use of either Ariane or 2-4D at 1.5times the registered rate of application should be encouraged to farmers for the management of weeds in finger millet.

Key words: Finger millet; Herbicides; Weed management, Crop yield

1 Introduction

Finger millet (*Eleusine coracana* L.) is an under-exploited minor millet with several edible and industrial uses. In Africa it's an important food security crop, with several local names all over the

world. The major producers are India, Nigeria, Niger, Mali, Burkina Faso, Chad and China (Chandra *et al*., 2018). Efforts to promote finger millet production have been constrained by weed infestation among other constraints like drought and low soil fertility. Apart from expensive labor costs associated with manual weeding, timely availability of labor is crucial in undertaking manual weeding (Shanmugapriya *et al*., 2020). The magnitude of losses caused by weeds depends on crop cultivars, nature and intensity of weeds, spacing, duration of weed infestation, edaphic and climatic factors and management practices followed. Weeds that emerge with or before the crop are the most competitive and result in the greatest yield loss (Swanton *et al*., 2015).

Weeds that emerge later than the crop are less competitive in terms of crop yield loss but still may be considered problematic if they affect the harvesting of crop or reduce the quality of economic produce. If weeds are not controlled and left to grow unhindered, they can affect overall growth and vigour, yield and biomass since weeds can draw more nutrients at a faster rate than the crop during the initial growth stages of the crop (Sneha & Sheeja, 2022). Similar to findings by Mishra and singh, (2012) observed that weeds removed about 31.59, 6.56 and 30.38 kg ha^{-1} of N, P and K from unweeded plots. They also observed that adoption of weed management practices significantly increased the nutrient uptake in sorghum. Similarly, Ramesh *et al*. (2019) also reported that weeds depleted 47.73 kg N, 31.19 kg P and 39.89 kg K ha^{-1} in pearl millet. They noted that there was considerable difference among the weed species in nutrient uptake. In related studies, Sikora and Cerovski, (2021) reported that for the production of unit quantity of dry matter, broad leaved weeds removed more amount of nutrients than the sorghum crop.

To realize higher productivity of finger millet, the major constraints limiting finger millet productivity in farmers' fields need to be addressed and weeds are a major constraint and limit productivity as initial slow growth as they compete for sunlight, nutrient and water in early stages of growth (Pradhan *et al*., 2010, Brahmachari *et al*., 2018). Weeds associated with finger millet have the ability to adjust to fluctuating edaphic and climatic situations. In order to enhance the productivity, reduce production cost and increase profitability of finger millet farming, complete understanding of associated weeds and adoption of appropriate weed management practices is important. In several related studies, Prithvi *et al*. (2015), Gupta *et al*. (2017), Rao and Chauhan (2015) and Ramadevi *et al*. (2021) noted that in unwedded fields, weeds smother the finger millet resulting in significant reduction in the yield by 5 to 70% depending on the agro climatic conditions, associated weed flora and cropping systems adopted. Nanjappa and Hosmani (1985a) noted that grain yield of finger millet decreases linearly with increase in weed population in India while Sidar and Thakur, (2000) noted that weeds caused high reduction in density, dry weight and nutrients uptake of finger millet. Weed population and weed biomass of 295/m^2 and 239 g/m^2, were reported to cause 47% reduction in yield in transplanted finger millet, respectively (Bhargavi *et al*., 2016). Grasses were found to be more competitive than sedges or broad-leaved weeds and weeds removed 50% of fertilizer N when weeding was delayed until 65 DAS (Nichols *et al*., 2015). Mishra, (2015) and Rao, (2021) noted that critical period of crop-weed competition (CPCWC) needs to be determined since this is a critical period to control weeds using herbicides or hand weeding, as it is one of the first steps in designing a successful integrated weed management. In related study, Naik *et al*. (2001) noted that the CPCWC for the finger millet varied from 25-60 days after sowing (DAS).

Herbicide usage has been reported to be the most effective and economical method for weeds management (Westwood *et al*., 2018). Herbicides can either be applied as a pre-emergence or post-

emergence herbicides. Pre-emergence herbicides are herbicides that are applied prior to weed seedling emergence while post emergence herbicides are applied after they have emerged above the ground. The uncontrolled weeds smoother finger millet resulting in significant reduction of yields of up to 70% (Rao, 2021). Also, weeds associated with finger millet production have as well as the ability to adopt to different climatic conditions. The critical period for crop weed competition in finger millet varies from 25-60 days after sowing (Chaudhary *et al*., 2018). Chauhan and Abugho (2012) reported that post - emergence herbicides provide an opportunity to control weeds and this may help increase growers interest in conservation agriculture in the near future.

The most dominant method of controlling weeds is by mechanical weed control which is becoming uneconomical due to higher labor charges. Shubhashree and Sowmyalatha (2019) found out that hand weeding caused control of weeds which resulted in higher grain yield as compared to unweeded plots. Small- holder farmers prefer this practice, as it is efficient where labor is cheaper and easily available. However, during labor peak periods, the crop may suffer losses due to labor unavailability during critical time of crop-weed competition. Shekhawat *et al*. (2020) found out that labor requirements reduced by 21% upon application of post emergence herbicides as compared to cultural operations.

Herbicides provide a crop with a greater advantage and a competitive edge over the emerging weeds. Kumar. Pawar *et al.* (2021) showed 2, 4-D amine salts was effective in controlling and enhanced yield upto 43% over the weedy check. Hayyat *et al*. (2016) reported that application of MCPA controlled broadleaf weeds in wheat. Greatest limitation in use of herbicide in finger millet is that no herbicide has been formulated or registered exclusively for the control of weeds in finger millet. In the present study the effectiveness of pre-emergence and post emergence herbicide were assessed for management of weeds of weeds in finger millet.

2 Materials and Methods

The field experiment was conducted at ATC Koibatek and ATC Soin in Baringo and Kericho respectively in the Rift valley region of Kenya. ATC Koibatek lies 0^0 8`N $36^0$ 2` E in agro ecological zone iv and an altitude range of a between 1890 meters above sea level (AMSL). It receives an annual precipitation of 700-900 mm per year with a mean temperature of 24.3^0 C. The soils are dark colored soils with high clay content and are classified as *vertisols.* Soin Sub County lies between in agro ecological zone III and altitude range of 1500 meters above the sea level. It receives annual precipitation of between 1300-1580mm with a mean daily temperature of 22^0C. The soils are classified as *histosols* and are usually saturated with water creating anaerobic conditions causing faster accumulation of organic matter (Jaetzold *et al*., 2010). The experiment was laid in Randomized Complete Block Design. Plots size was 2m × 3.2m with 1m separation between each plot. Two varieties of finger millet namely; Egerton snapping and U-15 were sourced from Egerton seed unit. Egerton snapping was selected because of its faster maturity characteristic and ease during harvesting manually. Variety U-15 was selected because of its color that is preferred by most farmers were planted with an equivalent seed rate of 8kg per hectare and a spacing of 40cm drilled at depth of 2-3cm. At planting N: P: K (23:23:0) fertilizer was applied at rate of 60 Kg N ha^{-1} and 60 Kg P_2O_5 ha^{-1}. Thinning was done to 5-7.5cm intra row spacing. Topdressing of was done at the seventh leaf stage using calcium ammonium nitrate (CAN)

fertilizer at the rate of 60 kg N/ha. The fields were not sprayed with any pesticides during the whole experimental period.

The experimental treatments included seven commercially available herbicides in Kenya namely Lumax, Dual gold, Primagram, 2-4D, Maguguma, Sencor and Ariane as shown in (Table 1). The treatments were compared to unweeded control where no herbicide was applied or any other weed management measures was not applied. A guard row was considered at the edge of experimental plots. Each of the plots consisted of eight rows of crops. First and the last two rows of each plot were planted with sorghum. In each plot there was a total of four rows of finger millet in between four rows of sorghum. These were included to avoid herbicide drift onto the next plot. Herbicides were sprayed using a hand sprayer in each plot. The pre-emergence herbicides were applied at planting while the post-emergence herbicides were applied 14 days after planting (DAP). The application rates were followed as per the manufacturer's recommendation. During spraying polythene bag was used to cover each plot to avoid herbicide drift.

Table 1: Active ingredients and dose rates of herbicides used in the study

Trade name	**Rate of application(L/Ha)**	**Active ingredient**	**Application timing of Herbicide**
Lumax	4l/ha	Metolachlor Terbuthylazine Mesotrione	Pre- emergence
Dual gold	1.6l/ha	S-metolachlor	Pre- emergence
Primagram	3l/ha	S-metolachlor Atrazine	Pre- emergence
2-4D	1.3l/ha	Dmethylamine Diethynolamine	Post-emergence
Maguguma	1.5l/ha	Atrazine S-Metolachlor	Post-emergence
Sencor	1l/ha	Metribuzin	Post-emergence
Ariane	1.25l/ha	Fluroxypyr Chlorpyrlid MCPA	Post -emergence

Weed count was done by placing $1m^2$ quadrat randomly twice in each plot and counting all the weeds appearing within the quadrat. Counting was done at the early and late vegetative stages. Weed density was determined using the formula of Maszura *et al*. (2018).

Weed biomass was estimated by uprooting weeds sample per plot all the plots, oven dried the sample and dry weight determined

$$Wd = \frac{Nw}{A\,Q} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ equation 1}$$

Where Wd =weed density, Nw =Number of weeds in a quadrant and AQ =Area of the quadrant

Weed control efficiency was determined using the formula suggested by (Kaushik & Mani., 1973)

$$\frac{Dww - Dwt}{Dww} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

Where, Dww = Dry weight of weeds weedy plots and Dwt =Dry weight weeds in treated plots.
Weed species abundance were determined by randomly placing a $1m^2$ quadrat in each plot. The species were identified using pictorial aids (e-library). All the individual species that were inside the quadrat were counted in the ratio of one species to the total number of all the species inside a quadrat.

$$Wsa = \frac{Nsq}{Tns} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3}$$

Where, Wsa=Weed species abundance, Nsq = Number of specific species in a quadrant, Tns = Total number of species in a quadrant.
Crop phytotoxicity was observed 7, 14 and 21 days after application of herbicides through visual observation using Jiddimani *et al*. (2017) Crop Phytotoxicity scale as shown in (Table 3.2).

Plant stand count was taken after thinning. Days to 50% flowering was done by taking the mean of ten randomly selected finger millet plants from the plot and counting the number of days from sowing to when 50% of the plant flowered. Days to finger millet maturity was measured by taking the mean of ten randomly selected finger plants from the plot and counting the number of days from sowing to when 90% of the fingers of the plants had matured. Number of fingers per plant was taken by averaging ten randomly selected counting the number of fingers per plant. Plant height was measured at maturity in centimetres. Crop biomass was determined by sampling crop, oven dried the above ground biomass then determined its weight. The biomass was converted to kilograms per hectare. Yield was determined by harvesting the four rows. The total yield from each plot was then weighed and converted into kilograms per hectare using the equation:

$$y = \frac{wgp\ (kg) \times 10000m^2}{ha\ (0.48m^2)} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 4$$

Where, Y =yield, Wgp = weight grain per plot and Ha =Harvested area

3.4 Data Analysis

All data on total weed count and yield was first subjected to Shapiro Wilk test to check if distribution of the values were statistically different from normal distribution. Weed density data was transformed using $\sqrt{x + 0.5}$ before analysis. Weed species abundance, weed count, weed biomass, weed density and weed control efficiency were subjected to analysis of variance (ANOVA) using the general linear model procedure in SAS (SAS Institute version 9.4, 2002). Means were separated using Tukey's Honest Significant Difference (HSD) test $p \leq 0.05$.

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 5}$$

Where a_i is constant generated from the means, variance and covariance of order statistics, n is the sample size, $x_{(i)}$ is the ordered sample values.

Data on weed species abundance was analyzed using the following model

$Y_{ijklmno} = \mu + E_i + S_j + R_k + H_l + S_m + HS_{im} + EHS_{ilm} + \varepsilon_{ijklmno}$ ……Equation 6

μ = the overall mean, E_i = the effect of environment in the i^{th} observation, S_j = effect of the season in the j^{th} observation, R_k = the effect of replication in the k^{th} observation, H_l =the effect of herbicide in the l^{th} observation, S_m = the effect of species types in the m^{th} observation, HS_{im} = the effect of interaction between herbicide and species types in the i^{th} and m^{th} observation, EHS_{ilm} = the effect of interaction between environment, herbicide and species type in the i^{th} ,l^{th} and m^{th} observation and $\varepsilon_{ijklmno}$ = the random error

Data on weed count, weed biomass, weed density, weed control efficiency was analysed using the following model

$Y_{ijklmno} = \mu + E_i + S_j + + R_k + V_l + H_m + G_n + HG_{mn} + EHG_{imn} + \varepsilon_{ijklmno}$ ……..Equation 7

where μ = overall mean, E_i = effect of the environment in the i^{th} observation, S_j = effect of the season in the j^{th} observation, R_k =effect of the replication in the k^{th} observation ,V_l = effect of the variety in the l^{th} observation , H_m = effect of herbicide in the m^{th} observation ,G_n =effect of growth stage in the n^{th} observation ,HG_{mn}= the effect of interaction between herbicide and growth stage in the m^{th} and n^{th} observation, EHG_{imn}=the effect of interaction between environment, herbicide and growth stage in the i^{t} ,m^{th} and n^{th} observation and $\varepsilon_{ijklmno}$ = the random error.

Data on crop biomass, phytotoxicity rating, yield and yield parameters was analyzed using the following model

$Y_{ijkmn} = \mu + E_i + S_j + R_k + V_l + H_m + ES_{ij} + ESH_{ijm} + \varepsilon_{ijklmn}$ (8)

Where, μ = overall mean, E_i = effect of the environment in the i^{th} observation, S_j = effect of the season in the j^{th} observation, R_k =effect of the replication in the k^{th} observation, V_l =effect of the variety in the l^{th} observation,H_m = effect of herbicide in the m^{th} observation, ES_{ij}= the effect of interaction between environment and season in the i^{th} and j^{th} observation, ESH_{ijm}=the effect of interaction between environment, season and herbicide in the i^{th},j^{th} and m^{th} observation and ε_{ijklmn} = the random error.

3 Results

Major weed species observed at both sites that affected finger millet production were *Biden pilosa, Amaranthus hybridus, Oxalis latifora, Datura stramonium, Commelina benghalensis, Galinsoga parviflora, Taraxacum officinale, Cyperus rotundus, Eragrotis pilosa, Digitaria scalarum.* Among the broad-leaved weeds were: *Biden pilosa, Amaranthus hybridus, Chenopodium album and Datura stramonium. Datura stramonium* and *Amaranthus hybridus* recorded the highest species population in weedy check. *Amaranthus hybridus* is reported to have allelopathic properties which can lead to a decrease in agricultural production (Yu *et al.*, 2022). *Biden pilosa* is one of the broad leaved that recorded higher species population. The maximum reduction of weeds numbers was recorded with lumax and sencor usag. Two troublesome narrow leaved weeds were recorded in the experimental plots these were *Cyperus rotundus* and *Eragrotis pilosa*. 2-4-D and Ariane had recorded the highest number of weeds of the Poaceae family. Dual Gold had the highest weed emergence by the time the crop was at it vegetative stage.

The analysis of Variance (ANOVA) results revealed that environment had significant effect on Weed species abundance $P \leq 0.05$. There was also significant difference in weed species abudance across the two sites with Baringo having a slightly higher number (20.39) than Kericho (19.83). Herbicides had a significant effect on weed species abundance at $P \leq 0.001$. Similarly, the weed species categories had a significant effect on weed species abundance at $P \leq 0.001$. The environment by season interaction recorded significant effect on weed species abundance at $P \leq 0.001$ as did species type by herbicide interaction on weed species abudance at $P \leq 0.001$. The three way interarction of environment by season by herbicide interaction was greatly significant at $P \leq 0.001$. There is no significant difference with the weed species abudance across the two season. There was significant difference in weed species categories that contributed to weed species abudance after herbicide application species belonging to Poaceae family (*Digitaria scalarum*, *Eragrotis pilosa* and *Dactyloctenuim agyptium*) had the highest weed species abudance of 34% those belonging to Fabaceae family that had a weed species abudance of 16% this shows that some herbicides could only control Fabaceae species leaving the Poaceae family hence making them to became dorminant. There was significant difference of weed species abudance after treatment. Lumax showed lowest weed species abudance of 0.1% this shows that it was able to control both broad leaved, narrow leaved and sedges weeds hence lowest weed species abudance. Control had the highest weed species abudance of 100%.There was no significant difference of weed species abudance between 2-4D and Ariane similary there was no significance difference of species abudance between Primagram,Maguguma and Sencor. Ariane had the highest weed species abudance of *Digitaria scalarum* (68.86%). There was no significant difference in the %weed species abundance of *Biden* pilosa, *Amaranthus hybridus* and *Oxalis latifora* across the two locations as shown in (Table 3.2).

Table 2: Effects of Location, Season on Weed Species Abundance

Location	**% weed species abudance**
ATC Baringo	20.39a
ATC Kericho	19.83b
Tukey MSD $_{0.05}$	0.47
Season	
Season 1	20.20a
Season 2	20.01a
Tukey MSD $_{0.05}$	0.47

Note:Means followed by the same letters are not significantly different.

The ANOVA revealed that environment had a significant effect on weed count and weed control efficiency at $p \leq 0.05$, weed biomass at $p \leq 0.001$ and weed density at $p \leq 0.01$. Seasons had a significant effect on weed biomass, weed density at $p \leq 0.001$ and weed count at $p \leq 0.05$ but no significant effect on weed control efficiency. Variety had a significant effect on weed count at $p \leq 0.05$, weed biomass at $p \leq 0.001$ and weed density at $p \leq 0.01$, however there was no significant effect of variety on weed control efficiency. Herbicides had a significant effect on weed count, weed density, weed biomass and weed control efficiency at $P \leq 0.001$ as shown in (Appendix 3) In addition environment by season interaction had a significant effect on weed biomass at $p \leq 0.001$ and weed density at $p \leq 0.05$. Growth stage had a significant effect on weed biomass, weed control efficiency and weed density at $p \leq 0.001$ but no significant effect on weed count. Environment by herbicide interaction had a significant effect on weed biomass at $p \leq 0.01$. Environment by growth stage interaction had a significant effect on weed biomass at $p \leq 0.001$.Growth stage by herbicide interaction had a significant effect on weed count and weed density at $p \leq 0.05$,weed biomass and weed control efficiency at $p \leq 0.001$.

There was a significant difference in weed count across the two environment. Kericho had a slightly higher weed count of 6.49/m^2 while Baringo had a weed count of 6.05/m^2. There was also significant difference in weed count across the seasons. Season one had a slightly higher weed count of 6.47 compared to season 2 which had a weed count of 6.08. There was significant difference in weed density across the two localities. Kericho had a higher weed density of 5.77 as compared to Baringo which had a weed density of 5.57. Similarly,there was a significant difference in weed density in between the two seasons. Season one had a slightly higher weed density as of 5.82 compared to season two which had a weed density of 5.52. There was no significant difference of weed density in Baringo in the two seasons. There was a significant difference in weed biomass across the two localities. Kericho had a higher weed biomass of 3.34g/m^2 as compares to Baringo which had a weed biomass of 3.04g/m^2. In addition, there was a significant difference in weed control efficiency of the two localities. Baringo had a weed control efficiency of 76.48% while Kericho had a weed control efficiency of 75.16%. In season one the weed biomass was 2.96g/m^2 which differed significantly when compared to season two which had a weed biomass of 3.44g/m^2. No significant difference in the weed control efficiency was experienced during the two growing seasons. Nakuru finger millet 1 varieties was associated with a higher weed biomass of 3.12g/m^2 compared to 3.08g/m^2 for U-15 that was not significantly different. There was no significance difference in weed count across the varieties Nakuru Finger millet 1 and U-15. Similarily, there was no signifacant difference of weed density across the two the finger millet varieties as shown in (Table 3).

Table 3: Effects of season, location and Varieties on weed count weed density weed biomass and weed control efficiency

Location	Weed count(n/m^2)	Weed density	Weed biomass	%WCE
Baringo	6.05±0.57b	5.56±0.08a	3.04±0.31a	76.48±2.24b
Kericho	6.49±0.58a	5.76±0.09b	3.34±0.34b	75.16±2.25a
Tukey MSD $_{0.05}$	0.34	0.16	0.11	1.26
Season				
Season 1	6.08±0.55b	5.82±0.09b	2.96±0.29a	75.93±2.18a
Season 2	6.47±0.61a	5.52±0.08a	3.44±0.37b	75.66±2.24a
Tukey MSD $_{0.05}$	0.34	0.16	0.11	1.26
Varieties				
U-15	6.11±0.58a	5.56±0.40a	3.08±0.22a	75.15±5.42a
Nakuru FM1	6.45±0.59a	5.77±0.42a	3.12±0.24a	76.46±a
Tukey MSD $_{0.05}$	0.75	0.31	0.02	2.10

Note: Means followed by the same letter along the column are not significantly different.

There was no significant difference in weed count and weed density across the two growth stages as shown in (Table 4). Late vegetative stage of the crop is associated with higher weed biomass of 3.64g/m^2 as compared to early vegetative stage of the crop which had a biomass of 2.75g/m^2 due to longer periods of herbicides exposure as shown in (Table 4) similarily, the late vegetative stage of the crop recorded a higher weed control efficiency 78.44% compared to the early vegetative stage of the crop.

Table 4: Effects of Growth stage on Weed count Weed density Weed biomass and Weed Control efficiency

Growth stage	Weed count(weeds/m^2)	Weed density	Weed biomass(g/m^2)	%WCE
Early vegetative stage	6.24±0.42a	5.92±0.07a	2.75±0.22b	73.13±5.29a
Late vegetative stage	6.31±0.70a	5.41±0.09a	3.64±0.41a	78.44±5.65b
Tukey MSD $_{0.05}$	0.34	0.06	0.11	1.26

Note: Means followed by the same letter are not significantly different.

There was a signifanct difference in weed count across the herbicides Lumax had the lowest weed count of (1.0/m^2) as shown in (Table 3. 10) However, was no significance difference in weed counts between Primagram,2-4-D,Sencor, Ariane and Maguguma, there was significant difference in weed counts between Dual Gold and the rest of herbicides. No herbicide application had the highest weed count of (24.46/m^2) as shown in (Table 3.10).Similarily, there was a significant difference in weed density across the herbicides treatments. Lumax had the lowest weed density of 4.75 while no herbicide application had the highest weed density of 7.30 as shown in (Table 3.10). There was no significant difference in weed density between Primagram, Sencor and 2-4D similarily, there was no significant difference in weed density between Maguguma and Ariane However there was significant difference in weed density between Lumax and Dual Gold Also,

there was significant different between Dual Gold and Ariane. The highest weed biomass was recorded for the control where there was no herbicide application. Weed biomass in plots that received Lumax was low at 0.71g/m^2 and differed significantly with other herbicides. Similarities in weed biomass were experienced in Primagram, Sencor,Maguguma,Ariane and 2-4D herbicides as shown in (Table 3.10). Weed control efficiency also was significantly different across the herbicides Lumax recored the highest weed control efficiency of 91.3% while the lowest was Dual Gold which had 67.22% there were no significant differences in the weed control efficiency of Primagram,Sencor,Maguguma Ariane and 2-4-D (Table 5).

Table 5: Effects of Herbcides on Weed count Weed density Weed biomass and Weed control efficiency

Herbicides	**Weed count (n/m^2)**	**Weed biomass (g/m^2)**	**Weed density**	**%WCE**
Primagram	3.08±0.26b	1.40±0.06b	5.58±0.11a	88.34±0.89a
Lumax	1.00±0.13a	0.71±0.08a	4.75±0.15b	91.34±2.12a
Dual Gold	11.77±0.51c	4.64±0.28c	6.52±0.13c	67.23±1.17b
Sencor	2.44±0.25b	1.17±0.08b	5.30±0.13a	89.92±0.91a
Maguguma	2.33±0.25b	1.18±0.07b	5.20±0.13ab	90.13±0.89a
2-4D	2.81±0.25b	1.35±0.05b	5.47±0.11a	88.88±0.70a
Ariane	2.40±0.27b	1.09±0.09b	5.23±0.13ab	90.56±0.94a
Control	24.46±0.82d	14.07±0.63d	7.30±0.17d	0.00±0.00c
Tukey MSD $_{0.05}$	1.05	0.36	0.49	3.91

Note: Means followed by the same letter along the column are not significantly different.

In Kericho early vegetative stage was associated with higher weed density of 6.21 as compared to late vegetative stage which had a weed density of 5.13 as shown in (Table 3.11) Similar trends were observed in Baringo. There was no significant difference in weed count, weed biomas, weed density and %WCE after treatment by both the herbicides in the two environments. In Kericho the first season had a slightly higher number of weed density than in the second season

Analysis of Variance revealed that environment had a significant effect on Days to maturity (DAM) and Days to grain filling (GFD) of the crop ($p \leq 0.001$). Seasons had a significant effect on crop stand, Days to 50% flowering (DTF), Days at maturity and Days to grain filling ($p \leq 0.001$) similarly, season had a significant effect on yield of the crop ($p \leq 0.01$) and number of fingers ($p \leq 0.05$). Environment by Season interaction had a significant effect on Days to maturity of the crop and Days to grain filling of the crop ($p \leq 0.\ 001.$) Variety had a significant effect on the number of tillers ($p \leq 0.05$). Environment by Variety interaction had a significant effect on Days to maturity and Days to grain filling ($p \leq 0.001$) similar trends were observed for Season by Variety interactions. The three-way interactions Environment by Variety by Season had a significant effect on number of fingers and tillers ($p \leq 0.05$). Herbicides used had a significant effect on crop phytotoxicity and all the yield and yield parameters ($p \leq 0.001$). The two-way interaction, Environment by Herbicide had a significant effect on Days to maturity ($p \leq 0.001$) and Days to grain filling ($p \leq 0.01$). Season by Herbicide interaction had a significant effect on number of tillers and plant biomass ($p \leq 0.001$) and on Days to maturity and Days to grain filling ($p \leq 0.01$). The three-way interaction Environment by Season by Herbicide had a significant effect on Days to flowering, Days at maturity and Days to grain filling ($p \leq 0.001$) and also on crop stand ($p \leq 0.05$).

There were significant differences in the plant biomass, Days to grain filling and Days to maturity of the crop between the two environments. Kericho had a higher biomass of 1.32t/ha when compared to that of Baringo at 1.24 t/ha. Regarding Days to maturity for Baringo, it took 111days to attain maturity as compared 114 days for Kericho to attain maturity similar trends are observed with 30days to grain filling for Baringo while in Kericho it took 33 days. Season two was associated with higher number of fingers (21.94) as compared to season one which had (20.77) fingers. In addition, greater crop stand was observed in season two (1447048/ha) as compared to season one (1374782/ha). In the second season the grain yield was 2.28t/ha which differed significantly when compared to season one at 2.05t/ha. Similar trends were experienced in the crop biomass where season two had a crop biomass of 1.45t/ha as compared to season one where the crop biomass was 1.11t/ha. There were significant differences in both 50% days to flowering, Days to maturity of the crop and Days to grain filling of the crop in the two seasons. In season one days to 50% flowering was 80 as compared to season two where the crop took 81 days to attain 50% flowering. Maturity of the crop in season one was 112 days after sowing (DAS) which differed significantly with season two where the maturity of the crop was 114days. Season one was associated with shorter days of grain filling (30 days) as compared to season two where the crop took (33 days) to grain filling.

There were significant differences in the yield obtain among the herbicides. Highest yield was obtained where Ariane was used (5.4t/ha) However, it was not statistically different from the yield obtained were 2-4D was used. Lowest yields were obtained where Lumax was used. There were no significant differences between the yields obtained where Maguguma, Primagram, Sencor and weedy check. Crop biomass was greatly influenced by the herbicide used. Higher crop biomass was associated with Ariane and 2-D. Dual Gold recorded crop biomass of 2.19 t/ha that was significantly different from biomass recorded where Maguguma was used (0.8 t/ha) or where Sencor was used (0.7t/ha). Use of herbicides in controlling weeds of finger millet severely affected the crop stand. Severe stand loss was observed where Lumax was used; hence no crop stand as shown in (Figure 3.1b). Ariane and 2-4D had no crop stand loss. Among the pre-emergent herbicides used Dual Gold had the least effect on crop stand. In addition, there was no significant difference in the stand count between Primagram, Sencor and control. Lumax recorded the highest crop phytotoxicity and that was characterized by severe stand loss and longer residual effect. Dual Gold had the lowest crop phytotoxicity amongst the pre-emergence herbicides. This was characterized by some stand loss. Use of Maguguma or Sencor had a significant effect on crop phytotoxicity However Ariane and 2-4D recorded no crop phytotoxicity.

Number of fingers was influenced by crop stand which was affected by the herbicides applied. More fingers were observed in Ariane and 2-4D where there was no stand loss. An increased plant height was recorded where weeds were controlled the greatest plant height was recorded where Ariane and 2-4D were used while no herbicide application equates to low plant height. There was no significant difference in grain filling days among the herbicides and weedy checks shown in (Figure 3.1h) However, there was significant difference in 50% days to flowering among the herbicides. The application of 2-D or Ariane resulted in the crop attaining 50% flowering earlier as compared to use of either Primagram or Sencor. In no herbicides application crops attained 50% flowering late. Due to significant stand loss after Sencor and Maguguma treatment fewer tiller were observed. There were no significant differences in the days to maturity of the crop among the herbicides. Crops matured late where no herbicides application was used. In season one in Baringo the grain yield was 2.29 t/ha that was not significantly different from the yield obtained

in Kericho during season one. Grain yield showed a significant positive correlation with crop biomass (r=0.98). In addition, stand count had a significant positive correlation with grain yield (r=1). Plant height had a positive correlation with yield (r=0.48) but that was not significant.

Discussion

High weed densities were recorded in *Datura stramonium* and *Amaranthus hybridus*. This is attributed to the fact that *Datura stramonium* grows rapidly and leading to its ability to outcompete water, light and nutrient requirement (Karimmojeni *et al*., 2021). High numbers of *Amaranthus hybridus* could be as a result of them producing many seeds under favorable conditions. *Biden pilosa* is fast growing, very invasive and has allelopathic compounds and because of this, it has high potential to reduce drop yield (Mahmoud *et al.,* 2015). 2-4D had the highest number of weeds from the Poaceae family his could be as a result of their active ingredients dmethylamine and diethynolamine that provides acceptable control of broad leaves but no control of the Gramineae. This result confirms that of Hassan *et al*. (2008) that showed dmethylamine and diethynolamine controlled broad leaves but no control of the Poaceae weeds. 2-4D is a synthetic plant hormone that mimic the natural plant hormones. A higher concentration of the synthetic plant hormones causes uncontrolled and unstainable growth causing stem curl-over, leaf withering, and eventual plant death (Davis, 2010). At 23 Days After Treatment application (DAT), weeds in the plots that were sprayed with Dual Gold had started emerging. There was therefore need for another weed control strategy which could be as a result of its shorter residual effect as compared to other herbicide like O'Connel *et al.* (1998) reported that Dual Gold its active ingredient (S-metolachlor) had a residual effect of 23 days. Lumax and Sencor were effective against reducing both broad and narrow leaf weeds. Fuerst, (1987) reported that in wheat, Lumax and Sencor act by inhibiting early seedling growth of the weeds. In addition, Ariane was effective against reducing the broad leaf weeds as shown in Table (3.3). These results confirm those of Magnoli *et al.* (2020) who found that application of Ariane at 1.25l/ha controlled broad leaf weeds in wheat.

The results this study showed a significant ($p<0.05$) reduction in weed species abundance, weed count, weed biomass and weed density after treatment by all herbicides used as compared to no herbicides application. All the herbicides used showed to have a significant weed control efficiency (WCE) ranking from Lumax with the highest WCE to dual gold with the lowest WCE Some herbicides caused crop injury that persisted for a longer period of time or greatly reduced the crop stand. Significant reduction in weed species abundance, weed count and weed biomass in Primagram can be attributed to their active ingredients (S-metolachlor and Atrazine). S-metolachlor negatively interferes with seedling development through inhibition of initial development (Silva *et al.,* 2020). In the case of Atrazine, it acts as a photosystem inhibitor II (Choe *et al*., 2014). This herbicide affects the electron transport in photosystem II that disrupts the photosynthetic process of weeds However, the herbicide is associated with high crop toxicity levels. A combination of S-metolachlor, Atrazine and Mesotrione had the highest weed suppression and the ability to suppress weeds 60DAT. However, it recorded the highest stand loss and crop phytotoxicity this could be attributed to the inability of finger millet seeds to metabolize the herbicide differently from other weed seeds hence the herbicide suppresses other weeds. Sencor (Metribuzin) cause inhibition of enzyme activity and protein synthesis which results in inhibition of weed growth. Dual Gold had the lowest weed control efficiency among the pre-emergent herbicides used and did not have a longer residual effect. According to Chepkoech *et al*. (2021) Dual Gold (S-Metachlor) are non-persistence However, it had the lowest crop phytotoxicity

and was agronomically acceptable. This could be attributed to the fact finger millet seeds was able to detoxify S-Metachlor hence less crop losses and damages (Choudhary & Lagoke, 1981).

The differences in weed suppression amongst the herbicides could be attributed to properties of individual herbicides such as solubility, photo degradation and persistence. Pre-emergence herbicides kill weeds before they emerge. Once the seeds come in contact with the herbicide they cannot germinate (Mitchell *et al*., 2001). Application of Sencor 1litre/ha (Metribuzin) recorded lower weed biomass as compared to no herbicide's application. These results confirm the findings of Kumar *et al.* (2014) who found that dry weight of sugarcane weeds was significantly reduced after application of Metribuzin. In no herbicide application, weeds grow uninterrupted and therefore they are able to maximize the available resources leading to a higher biomass.

Application of 2-4D at 1.31l/ha or Ariane at 1.25l/ha recorded lower weed biomass, weed count and ensured significant weed control efficiency In addition, there was no injury or damage to the crop these could be attributed to their differential herbicide metabolism which resulted in selectivity between crops and weeds the detoxicative activity of these active ingredient of the two herbicides is higher in finger millet than in weeds hence no injury to crop. Weed control efficiency implies the magnitude of weed reduction upon application of weed control treatment. Lumax being a non-selective herbicide had the highest weed control efficiency of both broad narrow leaf and broad leaf weeds this can be attributed by its combination of its active ingredient (S-metolachlor atrazine and Mesotrione) and the duration of their residuals activities these results are similar to that of sarangi and Jhala (2018) that showed a combination of metolachlor, atrazine and Mesotrione had the highest weed reduction at 42 DAT However, it had severe loss of the crop stand. In regard to stages, late growth stage of the crop had less weed count and weed biomass as compared to early growth stage because of longer periods of herbicides exposure hence no or few re-emergence of weeds. When finger millet is subjected to weed infestation during early growth stages it leads to a decline productivity of the crop (Mogaka *et al*., 2021). Therefore, weed control measures should be done early to avoid losses. Regarding the locality of Kericho it was associated with higher weed count, weed density and weed biomass this is due cool and wet conditions at Kericho while Baringo has a relatively warm and dry environment. Hence, weeds tend to emerge faster in Kericho than Baringo. In addition, the resources are readily available to initiate seed germination and translocation of synthetates leading to higher weed biomass.

Tillering ability of the crop was affected by the use of herbicide. Tillering of finger millet with no herbicide application was poor, in addition, application of 2-4D at 1.3 l/ha or Ariane at 1.25 l/ha yielded more tillers. Similar results were reported by Pradhan *et al*. (2010) who reported that there were more tillers in finger millet when chemical control was applied. Asargew and Shibabawu (2014) observed more tillers in plots where weed free condition were kept between 20-30 DAS. The increased finger millet height in treated plots could be as a result of reduction in crop-weed competition. Tippanagoudar *et al*. (2013) observed that millet acquired maximum growth due to good light interception, good root growth and nutrient acquisition as a result of reduced crop-weed competition.

Dry matter accumulation in crops differed significantly among the herbicides with no herbicides application recording the lowest dry matter accumulation as a result of severe competition for water, carbon dioxide and light leading to low biomass. 2-4D and Ariane recorded the highest dry matter accumulation. In presence of weeds, plant compete for resources that would hinder their

plant growth. Proper plant growth requires sufficient moisture, nutrients and carbon dioxide (Singh *et al*., 2015). Hence reduction in weed biomass provided an opportunity for utilization of resources that resulted in higher biomass. Muoni *et al*. (2013) concluded that herbicide application is the best weed control method to obtain higher yields.

Conclusions

The findings of the study showed that finger millet responded to post and pre-emergent herbicides differently. From the results, application of 2-4D or Ariane as post-emergent herbicides in finger millet showed significant weed control efficiency no phytotoxicity. Both herbicides had higher crop biomass which resulted in higher yields. Application of Dual Gold as a pre-emergent herbicide is not economical to farmers for 23 Days after Treatment application another weed control strategy should be applied since the residual effect of the active is over. Use of herbicides is an alternative method of weed control for increased crop yields as compared to hand weeding which has drudgery especially women who are main finger millet growers. A successful weed control using post-emergence herbicide is advantages to farmers as it helps them to realize increased yields.

CONFLICTS OF INTERESTS

The authors have not declared any conflicts of interests

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Effect of Butternut Squash (Cucurbita Moschata) Seeds Powder on the Chemical and Rheological Properties of Stirred Cultured Camel Milk and Yoghurt

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Abstract

Stirred fermented camel milk products are difficult to produce because of their weak texture and thin consistency, which makes them unpopular with consumers. Research conducted on camel milk revealed that during the coagulation process, only flocs were formed without firm coagulation, attributed to the lack of interaction between κ-casein and β-lactoglobulin, the large casein micelle size, leading to a weak network of casein formation. In an effort to address this issue, researchers turned to corn starch as a thickening agent, discovering that a concentration of 2.0% effectively improved the viscosity and significantly reduced syneresis in stirred camel milk yoghurt and stirred cultured camel milk. However, this study seeks to explore alternatives to corn starch, given its predominant role as a staple food in Kenya and its multifaceted applications across various industries. Butternut squash seeds being a by-product, presents a promising substitute to corn starch, given its abundant hydrocolloid composition. By incorporating butternut squash (*Cucurbita moschata*) seed powder (BSSP) as a thickener, this study aims to enhance the chemical and rheological properties of stirred camel milk yoghurt and stirred cultured camel milk. Stirred fermented camel milk product were prepared using 4 litres of camel milk, 2% starter cultures (thermophilic culture for yoghurt and mesophilic aromatic culture for stirred cultured camel milk) and BSSP 0.0% (negative control), 0.4%, 0.8%, 1.2%, 1.6%, 2.0% mixed with 0.4% gelatin. 2.0% corn starch mixed with 0.4% gelatin was used as a standard for comparison. Results show that increasing the BSSP level significantly ($p<0.05$) decreased the moisture content while increasing the total solid content of stirred fermented camel milk products. There was a progressive increase in ash content with increase in BSSP levels. There was a significant ($p<0.05$) reduction in the pH, with increase in BSSP levels in stirred fermented camel milk samples. Increasing the concentration of BSSP from 0.4% to 2.0% resulted in significant ($p<0.05$) increase in viscosity and a reduction in syneresis of stirred camel milk yoghurt and stirred cultured camel milk samples. This study demonstrates that BSSP effectively enhances the viscosity, reduces syneresis and increases acidity in stirred fermented camel milk products during storage.

Keywords: Corn starch, Butternut squash seed powder, Gelatin, stirred camel milk yoghurt, Stirred cultured camel milk.

1. INTRODUCTION

The limited availability of processed camel milk products in Kenya can be attributed to technical challenges and low consumer receptiveness. This is because it is challenging to replicate the viscosity of camel milk to match the familiar consistency of bovine milk that customers are accustomed to. Stirred fermented camel milk products are difficult to produce because camel milk does not coagulate well, resulting in a thin texture and frail product structure, with the gel texture being an important property in determining the mouthfeel, appearance and overall acceptability by

consumers in the modern market with a shift in preference to a particular texture, such as thicker mouthfeel (Seifu, 2023; Wong *et al.,* 2020).The weak firmness of camel milk coagulum can be attributed to lack of κ-casein and β-lactoglobulin interactions (Ho *et al.,* 2022); the large casein micelle size and low amounts of k-casein and high ratio of whey proteins to caseins, resulting in a fragile casein network that can easily be disrupted during coagulum formation (Berhe *et al.,* 2017).

Various dairy constituents (for example, whey protein concentrate) and hydrocolloids (for example starch and various gums) have been utilized to combat defects in fermented milk like syneresis, poor body and texture (Hematyar *et al.,* 2012). Hydrocolloids are non-digestible carbohydrates that have the ability to form gels or viscous solutions, thickening, emulsifying, coating and stabilizing (Hafezi & Pirsa 2023). Hydrocolloids consist of lengthy and complex molecules that can either interconnect internally or with other molecules in their surroundings to create an emulsion. They are hydrophilic polymers that have many hydroxyl groups and may be polyelectrolytes (Abdelmoneim *et al*., 2016). These polysaccharides work by interacting with the casein network and contribute to the formation of gels in a two-phase system (liquid-solid); a continuous, solid, three dimensional network structure forming the gel matrix holding finely dispersed liquid phase (Lunardello *et al.,* 2012). Addition of hydrocolloids maintains the morphological characteristics of yoghurt during transportation and storage by increasing its viscosity, absorbing water, strengthening and improving its texture. They are derived from animals, plants, microorganisms, or synthetic origins and are naturally present in foodstuffs (Pirsa & Hafezi, 2023). There is a rising need for hydrocolloids because of their capacity to create a stable emulsion system in dairy products, preventing whey separation and protein clumping throughout their shelf life (Javidi *et al.,* 2016). Through various mechanisms like covalent, electrostatic, excluded volume, hydrophobic interactions, van der waal forces, hydrocolloids combine with milk proteins to establish a gel network system, thereby enhancing the texture of dairy items (De Kruif and Tuinier, 2001; Wusigale *et al.,* 2020).

Only a small portion of Butternut squash is utilized directly for human consumption whereas the remaining portion (skin and seeds) is undervalued and treated as by-products and waste. These wastes can make important and valuable contribution to food resources and development of industrial products considering the abundant nutrition and technological properties contained in these residues (Li, 2020). A major issue encountered by many nations is handling waste especially from food products and agricultural produce. These waste has significant global environmental impact due its biodegradable nature and high water content contributing to pollution and has the potential to produce bad odour, abundant leachate (Liu *et al.,* 2012) and emit greenhouse gases (for example methane) in landfills (Cheng & Hu, 2010).

Butternut seeds boast a rich nutrition profile, featuring lipids, proteins, vitamins, phytosterols, minerals such as potassium, calcium and sodium and trace elements (Jiao *et al.,* 2014; Szterk *et al.,* 2010). Specifically, butternut squash seeds have a protein content of 32.38%, a fat content of 14.31% and a total phenolic content of 1.82 ± 0.05 mg GAE/g (Li, 2020). It also contains a fibre content 1.152 ± 0.20% and ash content of 1.152 ± 0.20% (Assilidjoe *et al.*, 2021). Wang *et al.* (2017) obtained polysaccharides from defatted butternut squash seed powder, the yield of crude polysaccharide was 2.3 %. Hydrocolloids from Butternut squash (*Cucurbita moschata*) seeds were evaluated as a stabilizer to preserve the physicochemical properties, flavour and texture of yoghurt samples. The addition of hydrocolloids from butternut squash seeds modified the rheology with positive effects on the texture, improved the physical stability and overall mouthfeel properties to

increase desirable sensorial attributes without any consequent appearance of undesirable effects (Rojas-Torres *et al.,* 2021). The researchers concluded that hydrocolloids from butternut squash seeds could be used as an additive for the formulation of microstructure food matrices. It can be utilized alone or blended with other hydrocolloids to increase viscosity or thickness and improve the water binding ability and texture of yoghurt.

There have been several attempts to remedy these challenges facing production of stirred fermented camel milk products. The reported approaches include using different gelling and thickening agents either alone or together (for example gelatin, corn starch, modified starch, bovine skim milk powder, polymerized whey protein isolate), hydrocolloids (for example xanthan gum, pectin, gum Arabic, alginate, gum acacia carboxymethyl cellulose, κ-carrageenan, sodium carboxymethyl cellulose) and other stabilizers such as calcium chloride Na_2EDTA and mono- and di-glyceride (Al-Otaibi & Al-Zoreky, 2015; Galeboe *et al.,* 2018; Hashim *et al.,* 2009; Ho *et al.,* 2022; Ibrahim & Khalifa; Jasim *et al.*, 2018; Kavas, 2016; 2015; Muhammad Imran, 2014; Muliro *et al.,* 2013; Oselu *et al.*, 2022).

This study examined how varying concentrations (0.4, 0.8, 1.2, 1.6, 2.0%) of BSSP affected the chemical composition of both stirred stirred camel milk yoghurt and stirred stirred cultured camel milk. The rheological characteristics of stirred camel milk yoghurt and stirred cultured camel milk was also studied for the 21 days of storage at 1, 7, 14, 21 days interval. Two controls were employed for this experiment; the negative control consisting of camel milk mixed with 0.4% gelatin and a standard consisting of camel milk mixed with 2.0% corn starch and 0.4% gelatin.

2. MATERIALS AND METHODS

2.1 Sample Collection

Fresh camel milk was procured from Marigat, Baringo county, Kenya. Fresh raw camel milk was conveyed in clean 20 litre containers to Department of Dairy and Food Science and Technology, Egerton University, Nakuru City, Kenya. Gelatin powder (beef skin), corn starch (Tri-Clover industries Kenya Limited) were all procured from Gilanis supermarket, Nakuru city, Kenya. Starter cultures (thermophilic and mesophilic) were procured from Promaco Kenya limited. Whole butternut squash seeds were obtained Vegpro Kenya Limited, Nairobi city, Kenya.

2.2 Preparation of Butternut Squash (*Cucurbita moschata*) Seeds

Fresh butternut squash seeds were collected from Vegpro Kenya limited during butternut squash processing, cleaned with distilled water and then oven dried at 65 ℃ for 12 hours as described by Li, (2020). The seeds were then powdered using a hammer mill and subsequently sieved using a no.30 sieve (600μm) in size to remove any coarse particles. Powdered butternut squash seeds were stored in a zip lock bags until use.

2.3 Preparation of Stirred fermented camel milk Products

Prior to making of stirred fermented camel milk products, all equipment was carefully cleaned and sterilized using hot water. Different formulations were employed to produce stirred fermented camel milk products as indicated in **Table 1**; this was achieved by altering the concentrations of

BSSP (0.4, 0.8, 1.2, 1.6, 2.0%), while maintaining the concentration of gelatin at 0.4%. Fresh camel milk mixed with 0.4% gelatin was utilized as the negative control and fresh camel milk mixed with 2.0% corn starch and 0.4% gelatin as the standard. Stirred fermented camel milk products (yoghurt and stirred cultured camel milk) was produced using steps outlined by Muliro *et al.*(2013); Oselu *et al*. (2022) but with minor changes. For stirred camel milk yoghurt samples, raw camel milk was pre heated to 65℃ to facilitate addition of dry ingredients (stabilizers). The mixture was then pasteurized in a thermostatically controlled water bath at 85℃ for 30 minutes then allowed to cool to 45℃ to facilitate inoculation of thermophilic yoghurt culture (Chr Hansen, YF-L903, Denmark) which consisted of strains of *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophillus*. Incubation was then carried out at 45℃ for 6h and refrigerated at 4℃ until the samples were analyzed. For stirred cultured camel milk samples, raw camel milk was pre heated to 65℃ to facilitate addition of dry ingredients (stabilizers). The mixture was then pasteurized at 85℃ for 30 minutes. The pasteurized mixture was then cooled to 25℃ to facilitate inoculation of mesophilic aromatic culture (Chr Hansen, CHN-22, Denmark) which consisted strains of *Lactococcus lactis subsp. Cremoris, Leuconostoc, Lactococcus lactis subs. lactis, Lactococcus lactis subs. lactis biovar diacetylactis*. Fermentation was carried out at 25℃ for 24h.

2.3 Chemical Properties

2.3.1 Determination of Total Solid Content

The weight of the residue obtained from analysis of moisture content in stirred fermented camel milk samples was used to calculate the total solids using the formula in equation 1 as described by Association of Official Analytical Chemists (AOAC, 2005, Method 925.23):

$$Total\ Solids\ (\%) = \frac{dry\ sample}{weight\ of\ the\ sample} \times 100 \quad \text{.....Equation 1}$$

2.3.2 Determination of Ash Content

The ash content of the stirred fermented camel milk products was determined following the AOAC (2005 Method number 930.05). 10 g of stirred fermented camel milk samples were weighed and transferred to a dry crucible. The samples were subjected to charring using a flame to decompose all organic components. Subsequently, the samples were ashed in a muffle furnace and incinerated at 550 ℃ for 6 h and cooled in a desiccator for 10 mins, the samples were weighed, and the ash content was calculated using the formula in equation 2:

$$Ash(\%) = \frac{weight\ of\ residue}{weight\ of\ sample} \times 100 \quad \text{.....Equation 2}$$

2.3.3 Determination of pH

The pH of stirred fermented camel milk products was determined using a pH meter (Adwa Instruments, Model 1020, Szeged, Hungary). The meter was calibrated using standard buffer solution of pH 4.0 and pH 7.0 and rinsed with distilled water.

2.4 Rheological Properties

2.4.1 Measurement of Syneresis

10ml of gelled stirred fermented camel milk product was centrifuged at 3000 rpm for 10 minutes at 10℃ according to (Muliro *et al.*, 2013) with slight modifications. The syneresis of stirred fermented camel milk products was determined at 1, 7, 14, 21 days. Measurement of susceptibility to syneresis was determined using the formula in equation 3:

$$Syneresis(\%) = \frac{Volume\ of\ separated\ whey}{10ml\ of\ fermented\ camel\ milk\ product} \times 100\% \text{.....Equation 3}$$

2.4.2 Measurement of Viscosity.

The viscosity of stirred fermented camel milk products was determined at 10℃ for stirred camel milk yoghurt and 20℃ for stirred cultured camel milk using DVELV viscometer (Brookfield Ametek, Model LV, Middlesboro, USA). Spindle no.63 and 20rpm (rotation speed) was used to measure 500 ml of stirred fermented camel milk products. Three replicates of stirred camel milk yoghurt and stirred cultured milk treatments were taken in centipoise units (cP)

2.5 Data Analysis

Data analysis was carried out using Statistical Analysis System (SAS Institute Inc., 2006) software Version 9.4 and Microsoft Excel (Version 2016). To test the study hypothesis, analysis of variance (ANOVA) was performed. The level of significance was established at $P<0.05$ confidence level and means separation was done using Tukey's Honest significant difference (HSD) method.

3. RESULTS AND DISCUSSION

3.1 Effect of BSSP on the Chemical Properties of Stirred Fermented Camel Milk Products

3.1.1 Total Solid Content

The total solid content values for stirred camel milk yoghurt samples ranged from 10.90% to 15.78% as shown in Table 1. Whereas stirred cultured camel milk samples ranged from 11.03% to 14.67% as shown in Table 2. Addition of BSSP significantly ($p<0.05$) increased the total solids content of stirred camel milk yoghurt samples and stirred cultured camel milk samples with 2.00% BSSP and 2.00% corn starch (standard) as a thickening agent having the highest values. Also, it was apparent that increasing BSSP concentration from 0.4 to 2.0 % significantly ($p<0.05$) decreased moisture content in stirred fermented camel milk products, conversely increasing the total solids. This could be attributed to the fact that BSSP contained hydrocolloids. Hydrocolloids are hydrophilic in nature and are effective in absorbing water by physically trapping free water and confining them in the increased network density and chemically by facilitating a link with other water molecules, thus increasing the gel-water binding capacity (Abdelmoneim *et al*., 2016; Bahrami *et al*., 2013).

Total solids content is a significant factor in the determination of the viscosity and rheological characteristics of yoghurt. Studies have indicated that higher total solid solids may result in improved viscosity, thus positively impacting the quality of yoghurt (Lussier *et al*., 2023*)*. Total solids are the most important technological property that determines the physical stability of yoghurt gel structure. Insufficient total solids fortification leads to wheying off and weak body (Mwizerwa *et al.,* 2017).

The average total solid content values reported by other researchers are as follows: 12.2% (Adel *et al.,* 2011), 16.65% (Galeboe *et al.,* 2018), 9.24% (Ibrahem & El Zubeir, 2016), 11.83% (Mustafa, 2015)

3.1.2 Ash Content

The ash content values varied from 0.23% to 1.08% for stirred camel milk yoghurt as shown in Table 1 and 0.23% to 0.953% for stirred cultured camel milk as shown in Table 2. Addition of \BSSP as a thickening agent significantly ($p<0.05$) increased the ash content of both stirred camel milk yoghurt and stirred cultured camel milk. Stirred camel milk yoghurt sample containing 2.0% BSSP and stirred cultured camel milk sample containing 2.0% BSSP had the highest percentage of ash content compared to other samples indicating that 2.0% BSSP is rich in minerals compared to corn starch when used as a thickener at the same concentration. Ash content is of significant importance as it serves as an indicator of the mineral composition within the product, thus contributing to its nutritional value and potential health benefits. The average ash content values reported by other researchers are as follows: 0.71% (Adel *et al.,* 2011), 1.13% (Galeboe *et al.,* 2018), 0.84% (Mustafa, 2015), 0.99% (Seifu, 2023).

3.2 Effect of BSSP on the Storage of Stirred fermented camel milk Products

3.2.1 pH

During storage, different treatments of BSSP had significant ($p<0.05$) effects on both stirred camel milk yoghurt and stirred cultured camel milk pH. During storage, the pH of the negative control in stirred camel milk yoghurt decreased from 5.02 to 4.88. The pH of the stirred camel milk yoghurt sample containing 2.0% corn starch decreased from 4.8 to 4.72. Samples treated with different concentrations of BSSP also decreased; the pH of the yoghurt sample containing 0.4% BSSP decreased from 4.81 to 4.70; the pH of the stirred camel milk yoghurt sample containing 0.8% BSSP decreased from 4.79 to 4.66; the pH of the stirred camel milk yoghurt sample containing 1.2% BSSP decreased from 4.77 to 4.61; the pH of the stirred camel milk yoghurt sample containing 1.6% BSSP decreased from 4.62 to 4.43; the pH of the stirred camel milk yoghurt sample containing 2.0% BSSP decreased from 4.59 to 4.40 after being stored for 21 days (Figure 1). In the case of stirred cultured camel milk, the pH of negative control decreased from 4.78 to 4.69. The pH of the stirred cultured camel milk sample containing 2.0% corn starch decreased from 4.69 to 4.60. Samples treated with different concentrations of BSSP decreased; the pH of the stirred cultured camel milk sample containing 0.4% BSSP decreased from 4.68 to 4.59; the pH of the stirred cultured camel milk sample containing 0.8% BSSP decreased from 4.67 to 4.55; the pH of the stirred cultured camel milk sample containing 1.2% BSSP decreased from 4.65 from 4.53; the pH of the stirred cultured camel milk sample containing 1.6% BSSP decreased from 4.62 to 4.51; the pH of the stirred cultured camel milk sample containing 2.0% BSSP decreased from 4.6 to 4.49 after being stored for 21 days (Figure 2). The continuous decrease in pH values could be attributed to conversion of lactose to lactic acid by lactic acid bacteria during fermentation and the subsequent storage period (1-21 days) (Al-Zoreky & Al-Otaibi, 2015; Hassaan *et al.,* 2019; Khalifa & Ibrahim, 2015; Oselu *et al.,* 2022; Sadler & Murphy, 2010). The decrease in pH can also be attributed to the ability of BSSP to retain water since it contains fibre thereby diluting the concentration of lactic acid and other organic acids produced by the starter cultures (Alqahtani *et al.,* 2023). There are several factors that can also reduce the pH of fermented milk including total soluble solids, additives and storage temperature (Dabija, 2018).

Increasing the concentration of BSSP from (0.4% to 2.0%), reduced the pH values in both stirred camel milk yoghurt and stirred cultured camel milk samples as shown in Figure 1 and 2. There was a progressive decrease of pH values for all stirred camel milk yoghurt samples and stirred cultured camel milk samples but the pH decrease for stirred camel milk yoghurt samples

containing 2.0% BSSP and stirred cultured camel milk sample containing 2.0% BSSP was significantly higher ($p<0.05$) than the negative control samples in both stirred camel milk yoghurt and stirred cultured camel milk samples. This could be due to the higher total solids content in stirred camel milk yoghurt samples containing 2.0% BSSP and stirred cultured camel milk sample containing 2.0% BSSP that may have hindered the movement of the liquid phase and influenced the activities of starter cultures to metabolize sugars , producing lactic acid and organic acids as the main metabolic end products (Galeboe *et al.*, 2018; Oselu *et al.*, 2022; Singh *et al.*, 2017).

These findings exhibited comparable trends to those observed by other researchers including; (Khalifa & Ibrahim, 2015; Oselu *et al*., 2022). The pH of stirred camel milk yoghurt decreased with increasing fermentation time from 0-6 hours and storage time from 1 to 21 days. The negative control yoghurt sample experienced a reduction in pH levels from 6.68 to 4.47 within a span of 6 hours, further declining to 4.4 after a period of 21 days. All stirred camel milk yoghurt samples treated with stabilizers decreased in their pH values after 21 days of storage (Oselu *et al*., 2022). The pH values of stirred camel milk yoghurt samples varied based on the type and amount of stabilizer added. Stabilizers caused a decrease in pH compared to the control samples, with the highest acidity observed in the stabilizer-treated stirred camel milk yoghurts. The decline in pH over time during storage was attributed to continued fermentation by lactic acid bacteria and the acidity contributed by the added stabilizers. This decline was more pronounced in stirred camel milk yoghurt containing stabilizers compared to the control (Khalifa & Ibrahim, 2015).

3.2.2 Syneresis

All stirred camel milk yoghurt samples and stirred cultured camel milk samples had a significant ($p<0.05$) decrease in their syneresis percentage in comparison to the negative control samples that did not contain any thickening agent in stirred camel milk yoghurt and stirred cultured camel milk samples, indicating that combining gelling agents and thickening agents reduced susceptibility to syneresis of both stirred camel milk yoghurt and stirred cultured camel milk samples. Combining both gelling and thickening agents improves the texture of fermented milk texture by promoting coagulum formation and because of the solubilization ability of gelatin, it increases the intermolecular interactions with the thickening agents, improving the viscosity and holding the gels together reducing syneresis (Muliro *et al.*, 2013).

During storage, the susceptibility to syneresis of the yoghurt control sample increased from 92.5% to 94.7%; stirred camel milk yoghurt sample containing 0.4% BSSP increased from 42.2% to 75.8%; stirred camel milk yoghurt sample containing 0.8% BSSP increased from 30.3% to 65.2%; stirred camel milk yoghurt sample containing 1.2 % BSSP increased from 21.3% to 60%; stirred camel milk yoghurt sample containing 1.6% BSSP increased from 13.5% to 53.7%; stirred camel milk yoghurt sample containing 2.0 % BSSP increased from 1.2% to 49%; standard stirred camel milk yoghurt sample containing 2.0% corn starch increased from 0 to 42.8% after being stored for 21 days. As for stirred cultured camel milk susceptibility to syneresis increased during storage, the control sample increased from 91.3% to 95.3%; the stirred cultured camel milk sample containing 0.4% BSSP increased from 39.8% to 73.8%; the stirred cultured camel milk sample containing 0.8% BSSP increased from 29% to 65.8%; the stirred cultured camel milk sample containing 1.2% BSSP increased from 21% to 60.3%; the stirred cultured camel milk sample containing 1.6% BSSP increased from 16% to 52.7%; the stirred cultured camel milk sample containing 2.0% BSSP increased from 2.5% to 48.7%; the standard stirred cultured camel milk sample containing 2.0%

corn starch increased from 0% to 43.2% after being stored for 21 days. Susceptibility to syneresis was significantly ($p<0.05$) reduced with increase in concentration of BSSP from 0.4% to 2.0%. This can be explained by the highly branched structure of BSSP, which could easily interact with gelatin and form bonds with the protein matrix in camel milk and ions in aqueous phase and water (Rojas-Torres *et al.,* 2021). These current results corroborate the findings of (Muliro *et al*., 2013; Oselu *et al*., 2022; Rojas-Torres *et al.,* 2021; Wong *et al*., 2020) who reported that increasing the concentration of stabilizers, using both gelling and thickening agents reduced syneresis. The decrease in syneresis of samples containing BSSP may also be attributed to gummy sugars in fibres, which can trap water. These findings also align with the outcomes reported by Arabshashi-Delouee *et al.,* (2020) for yoghurt containing flaxseed press cake and Alqahtani *et al.,* (2023) for yoghurt containing date press cake.

In summary, stirred camel milk yoghurt sample containing 2.0% BSSP and 2.0% corn starch and 2.0% BSSP and 2.0% BSSP in stirred cultured camel milk sample displayed significantly ($p<0.05$) lower syneresis percentage over the storage period (1-21 days) because of the higher concentration of thickening agents as compared to all the other stirred camel milk yoghurt and stirred cultured camel milk formulations. The negative control samples in both stirred camel milk yoghurt and stirred cultured camel milk samples exhibited high syneresis percentage over the storage period (1-21days). It was worth noting that there was a sharp increase in syneresis percentage on day 21 of storage in all the stirred camel milk yoghurt and stirred cultured camel milk samples as illustrated in (Figure 3 and 4). This could be attributed to reduction in total solids content over the storage period due to breakdown of macromolecules (Mwizerwa *et al.,* 2017)**.**

3.2.3 Viscosity

The viscosity values of stirred camel milk yoghurt and stirred cultured camel milk samples increased from day 1 to day 7 of storage, followed by a decline on day 14 and a sharp drop on day 21 of storage. There was no significant difference between the standard and stirred camel milk yoghurt sample containing 2.0% BSSP and stirred cultured camel milk sample containing 2.0 % BSSP but the standard had the highest viscosity values compared to BSSP when used as a thickening agent at the same concentration. This could be attributed to the gel -forming characteristics of corn starch that prompted interactions between casein micelles in camel milk and corn starch (Galeboe *et al.,* 2018; Oselu *et al.,* 2022; Singh *et al.,* 2017) and the difference in structure between BSSP and corn starch polysaccharide. The standard exhibited better and increased intermolecular associations forming stronger junction zones with gelatin that facilitated better gel reformation contributing to an increase in viscosity and reduced susceptibility to syneresis as compared to 2.0% BSSP mixed with 0.4% gelatin. It was worth noting that increasing the concentration of BSSP from (0.4 to 2.0%) significantly ($p<0.05$) increased the viscosity of both stirred camel milk yoghurt and stirred cultured camel milk during storage. This is because low levels of BSSP did not cover and interact with all the casein particles in camel milk to create sufficient electrostatic and steric repulsions to stabilize the dispersion but higher concentrations of BSSP could sufficiently interact with the casein micelles hence the higher viscosity values. The addition of hydrocolloids from butternut squash seeds influenced the viscoelastic parameters of the yoghurt, with significant differences observed in G’ and G’’ values among samples containing hydrocolloids from butternut squash seeds. The frequency sweep results revealed changes in the gel-like behaviour of the yoghurt samples, with hydrocolloids from butternut squash seeds

contributing to the formation of a strong gel structures and interacting with milk proteins (Rojas-Torres *et al*., 2021).

During storage, the viscosity values significantly ($p<0.05$) decreased from the day of processing to the end of storage. In stirred camel milk yoghurt, the viscosity of the negative control sample containing 0.4 % gelatin solely decreased from 34 cP to 26 cP; the viscosity of the stirred camel milk yoghurt sample containing 0.4% BSSP decreased from 179 cP to 85 cP; the viscosity of the stirred camel milk yoghurt sample containing 0.8% BSSP decreased from 422 cP to 221 cP; the viscosity of the stirred camel milk yoghurt sample containing 1.2% BSSP decreased from 619 cP to 362 cP; the viscosity of the stirred camel milk yoghurt sample containing 1.6% BSSP decreased from 827 cP to 443 cP; the viscosity of the stirred camel milk yoghurt sample containing 2.0% BSSP decreased from 1076 cP to 676 cP; the viscosity of the standard sample containing 2.0% corn starch decreased from 1404 cP to 850 cP after being stored for 21days (Figure 5). As for stirred cultured camel milk, the viscosity of the negative control sample containing 0.4% gelatin solely decreased from 50 cP to 32 cP; the viscosity of the stirred cultured camel milk sample containing 0.4% BSSP decreased from 147 cP to 87 cP; the viscosity of the stirred cultured camel milk sample containing 0.8% BSSP decreased from 431 cP to 249 cP; the viscosity of the stirred cultured camel milk sample containing 1.2% BSSP decreased from 602 cP to 365 cP; the viscosity of the stirred cultured camel milk sample containing 1.6% BSSP decreased from 784 cP to 438 cP; the viscosity of the stirred cultured camel milk sample containing 2.0% BSSP decreased from 957 cP to 577 cP; the viscosity of the standard sample containing 2.0% corn starch decreased from 1282 cP to 739 cP following 21 days of storage (Figure 6).

From the results of the present study there was significant ($p<0.05$) difference in stirred camel milk yoghurt and stirred cultured camel milk samples containing thickening agents and the negative control samples containing only a gelling agent indicating the important role played by thickening agents in improving and increasing the viscosity of stirred fermented camel milk products. Viscosity was low in gels formed with either gelatin or corn starch alone but combining both gelling and thickening agents improved the viscosity and reduced syneresis of stirred fermented camel milk products (Muliro *et al.,* 2013). These findings exhibited similar trends with those observed other researchers reporting that increasing concentrations of stabilizers, increased viscosity (Khalifa & Ibrahim, 2015; Muliro *et al.,* 2013; Oselu *et al.,* 2022; Rojas-Torres *et al*., 2021; Wong *et al.,* 2020). BSSP also contains fibre and several studies have also indicated that fortifying yoghurt with various dietary fibres enhances the viscosity and thickening characteristics of fermented milk (Alqahtani *et al.,* 2023; Karaca *et al.,* 2019; Varnaitė *et al.,* 2022).

Incorporating hydrocolloids sourced from butternut squash seeds as a stabilizer resulted in a decrease in apparent yield stress across all yoghurt samples, indicating intensified crosslinking of milk proteins in acidified milk, thereby impacting the yoghurt's structure under shear conditions. Research has showed that yoghurt samples exhibited non-Newtonian flow behaviour, whereas the apparent viscosity decreased as the shear rate increased, indicating shear-thinning tendency. The decrease in viscosity with increasing shear rate was attributed to the aligned flow of stiff polymer molecules, which reduced interactions between adjacent polymer molecules, which reduced interactions between adjacent polymer chains and disrupted the casein micelle network during shear application. Yoghurt samples containing hydrocolloids showed a two-step yield stress, indicating changes in the structural properties of the yoghurt matrix. The activation energy values of the yoghurt samples increased with the addition of hydrocolloids suggesting a higher

temperature dependence of viscosity in samples with higher hydrocolloid content (Rojas-Torres *et al*., 2021).

4. CONCLUSION

This study demonstrates the promising potential of utilizing discarded butternut squash (*Cucurbita moschata*) seeds as a thickening agent in the development of stirred fermented camel milk products. The inclusion of BSSP in stirred cultured camel milk and yoghurt samples resulted in significant ($p<0.05$) reduction in syneresis values and an increase in viscosity values compared to the control. Moreover, higher concentrations of BSSP proved to be effective in further enhancing viscosity and reducing syneresis these products. The incorporation of BSSP emerges as a viable and sustainable alternative, not only contributing to waste reduction by utilizing butternut squash seeds but also offering tangible benefits in terms of texture improvement in stirred fermented camel milk products. These results present an opportunity for the food industry, particularly those involved in the production of stirred fermented camel milk products, to consider innovative approaches for enhancing product quality and consumer satisfaction.

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The Effect of Cooking on Nutritional Characteristics of Biofortified Common Beans (*Phaseolus Vulgaris*) in Burundi

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Abstract

The study was conducted at the Guildford Dairy Institute, Department of Dairy, Food Science and Technology, Egerton University. The aim was to determine the effect of cooking on the proximate composition, anti-nutrient and minerals content of ten biofortified common bean from Burundi with varieties with variety Rusenyanzego and Kinure acting as controls. Standard methods were used to conduct analyses in the raw and cooked varieties. Cooking increased the protein content of *Kinure*, NUV30, NUV91, RWV1129 and *Rusenyanzego.* The fibre content of all varieties increased after cooking. There was a significant reduction in carbohydrate content in all biofortified bean varieties after cooking except for RWR2245. Cooking increased the fat content of all bean varieties except for NUV91 but reduced the condensed tannin content in all biofortified bean varieties. Cooking did not affect the phytic acid level in NUV91 (20.53 mg/100g) bean variety. There was a reduction in total phenolics content in varieties NUV30, RWR215 and RWV1129. Mineral concentration varied within the varieties. Cooking caused loss of Fe in RWR2154 (9.3%), NUV130 (71.3%), MAC70 (27.1%) and RWV1272 (26.7%) biofortified varieties but increased Fe concentration in RWV1129 variety by 68%. The Zn content other varieties but reduced by 12.4% in MAC70. Ca content decreased in NUV130, RWV1272 and MAC44 by 28.2%, 15.8% and 3.1% respectively. Conclusively, the cooking process either reduced or increased the nutrient and antinutrient factors in the common bean varieties hence impacting their nutritional composition. These varieties can be consumed and considerably alleviate malnutrition particularly in developing countries.

Keywords: Proximate, Nutritional value, Antinutrient, Minerals, Cooking

1.0 INTRODUCTION

Dried beans often referred to as grain legumes play a significant role in the diets of the global population. The common bean is estimated to be the third most important legume globally after soybean and peanut (Buruchara *et al*., 2011: Amongi *et al*., 2018). Furthermore, of all the edible

legumes, common beans are the most consumed by consumers (De Ron *et al*., 2015), have the widest geographical distribution, are the most cultivated, and have diverse morphology with genetic variability for protein concentration and specific seed protein components (Adesoye & Ojobo, 2012). In Africa, the crop is the most consumed legume with countries such as Burundi and Rwanda having a higher consumption of beans, ranging from 31 kg to 66 kg per year an equivalence of 180g per capita per day (Blair *et al*., 2010; HarvestPlus, 2014). The cultivation of common beans in these countries is both for subsistence agriculture and regional markets, hence playing an important role in food security and income generation (Buruchara, 2019).

Beans are nutritious crops rich in macronutrients, significant amounts of micronutrients including iron and zinc, and vitamins (Hayat *et al*., 2014). Beans are unique protein-rich foods, coupled with their high carbohydrate and low-fat content (Messina, 2014). In many developing countries beans provide a cheap source of proteins compared to meat and meat products (Nwadike *et al*., 2018a) and are thus recognized as poor man's meat(Oomah *et al*., 2011; HarvestPlus, 2014). Apart from their nutritional value, beans are a rich source of bioactive compounds such as phenolic compounds, oligosaccharides, enzyme inhibitors, and lectins, and have the potential to promote positive health outcomes (Samtiya *et al*., 2020). However, the amounts and concentration of the various nutrients vary significantly depending on the variety, region or cultivation environments (Hayat *et al*., 2014; OECD, 2015). On the other hand, consuming dry beans helps reduce the risks associated with the consumption of some animal proteins and is hence superior in the management and prevention of certain diseases such as hypercholesterolemia, hypertension, cardiovascular diseases, type II diabetes, and cancer, hence overall health (Chávez-Mendoza & Sánchez, 2017).

Biofortification is a process that involves genetic or agricultural modification of staple crops to improve their nutritional composition and other important agricultural traits such as resistance to diseases and increased yields (Bouis *et al*., 2011; De Steur *et al*., 2012; Gilligan, 2012). The availability of biofortified crops can lead to reduction in food prices due to an increase in the availability of variety of crops to cultivate and consume. Consequently, these crops contribute towards food and nutrition security and thus a reduction in macronutrient and micronutrient deficiencies (Bouis *et al*., 2011; Bouis *et al*., 2013)**.** Utilization of biofortified common beans is one of the strategies that are key in mitigating micronutrient malnutrition and related health complications. Additionally, biofortified common beans complement other nutrition-sensitive programs such as food fortification and supplementation (Buruchara *et al*., 2011; Katungi *et al*., 2020). For example, high-iron beans released in Rwanda provide about 30% of the estimated average requirements of iron among women and preschool children in almost 250,000 households (Bouis *et al*., 2013; Ngozi, 2013).

However, the common bean is not palatable in its raw state due to the presence of antinutritional compounds which requires cooking or processing prior to consumption. Cooking or processing of beans such as canning helps degrade a toxic compound known as lectin phytohemagglutinin, which is associated with severe gastric upset (Katungi *et al*., 2009). Tannins if un-degraded on the other hand can form complex compounds with proteins thus reducing amino acid availability and protein digestibility (Messina, 2014). Cooking legumes in general improves their nutritional value by reducing antinutrient, such as phytic acid and tannins, and promotes protein and starch digestibility. Cooking also imparts desirable sensory properties such as cooked-bean flavour, soft, sweet taste and mushy textures to the bean grains (Ranilla *et al*., 2009). The cooking processes though very crucial, can result in physical loss of nutrients through the leaching in cooking the

broth (Carvalho *et al*., 2012; Bechoff, 2017), thus exuberating micronutrient deficiencies even in regions with higher consumptions of these biofortified common beans.

Different varieties of biofortified common beans have been developed through conventional breeding and released to small-scale farmers in Burundi through the Pan African Bean Research Alliance Program (PABRA). Even though extensive research has been conducted assessing their agricultural traits, consumer acceptability studies, adoption by farmers and development of various bean-based products, there remains limited research on their nutritional composition particularly in Burundi(Harvest Plus, 2014, Mughi, 2017, Karungi *et al*., 2020, Glahn *et al*., 2020, Fungo *et al*., 2020; Mwangwela *et al*., 2021)**.** The aim of this study was to evaluate the proximate, mineral and antinutrient composition of nine biofortified common bean varieties and two traditional varieties grown and consumed in the country. This information will form a basis for the nutritional composition of these biofortified bean varieties and showcase any gaps that need to be addressed by bean breeders and other stakeholders in the common bean value chain.

2.0 MATERIALS AND METHODS

2.0.1 Selection of common bean varieties

A total of eight (8) biofortified common bean varieties recently released in Burundi and currently most preferred by farmers (Buruchara *et al*., 2011; Katungi *et al*., 2021) were obtained from grain retailers and smallholder farmers in reputable farmers in Burundi through the Institute des Sciences Agronomiques du Burundi (ISABU). These varieties included RWV1129 (Murengeti), RWV1272 (Mutwenzi), MAC44 (Magorori), and MAC70 (Rwizibigega), RWR2245 (Kaneza), and RWR2154 (Murwiza), NUV30 and NUV130, Kinure and Rusenyanzego (traditional non-biofortified varieties) were used as control. Kinure RWV1129 and RWV1272 are bush types while the other mentioned varieties are climbing bean types. This study aimed to utilise the most utilised bean varieties in Burundi. The common bean varieties were purposively selected by bean breeders due to their high concentration of iron and zinc and low concentration of phytic acid and preference by farmers for being high yielding. The Institute of Agricultural Science of Burundi (ISABU) issued a phytosanitary certificate, and the Kenya Health Inspectorate Service (KEPHIS) issued a plant importation permit with permit number KEPHIS/PIP/000248226. The samples were packaged in 2-kg weights and sent to Kenya via Dalsey, Hillblom, and Lynn (DHL) services in clearly marked translucent zip-top sample bags, and wrapped in a single opaque carton box. The beans were kept at room temperature in clear, sterile, airtight plastic containers at the Food Chemistry Laboratory of Egerton University for further analyses.

2.0.2 Sample preparation

About 150g of bean grains were sorted and prepared for analysis according to procedures described by Biama *et al*. (2020). Each variety was cleaned by removing any dirt and dust and rinsed in distilled water. Grains were then ground using a laboratory grinder and then stored at a temperature of 9+2°C until all analyses (pre-cooking analyses) were done. Regarding post-cooking analysis, bean grains of each variety were cooked using portable boiling water. Dry bean grains (150 g) were soaked in 1 L of distilled water for 16 h at 20°C. The soaking water was then discarded, and the soaked bean grains were put in granite pots with 1 L of distilled water and cooked in an open aluminium pot at 93.5ºC (the boiling temperature of water in Njoro). Evaporated water was replenished with hot water. Cooked beans were hand-squeezed for

tenderness and samples collected when fully cooked and cooled using ice and placed in refrigerator for 24 h at 4ºC before analysis (post cooking analysis).

2.0.3 Experimental design

The laboratory experiment was a (10×2) completely randomised design (CRD) in a factorial arrangement. The first factor was ten bean varieties, and the second factor was pre-treatment (Raw and cooked) beans. The experiment was replicated thrice.

2.1. Proximate composition analyses

Proximate composition was determined using standard AOAC methods. Total solids, crude protein, crude fat, ash, and crude fibre were determined according to AOAC (2012). The total carbohydrate content was determined by difference. The analyses were conducted in replicates.

2.1.1 Determination of moisture content

The moisture content of the uncooked and cooked ground bean grains samples was determined using the oven-drying method according to AACC International (2007), Method 44-15 A. This involved exposing samples to temperatures of 105˚C for 3hrs (single-stage) in the air oven. Moisture content was then calculated as the loss in weight expressed as a percentage of the original weight of a sample.

$$\% \text{ Moisture Content} = \frac{(\text{weight of pan+wet sample}) - (\text{Weight of pan+dry sample})}{\text{Weight of sample}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots 2$$

2.1.2 Determination of ash content

The AOAC (2000), method 942.05 was used to determine the ash content. About 2g of uncooked and cooked ground bean grains from each variety were weighed (W1) into a crucible that had previously been calcined and weighed (W2), and then heated in a muffle furnace (Model: MR170; S/N: 6800616; Hereaus GMBH, Hanau, Germany) at 550˚C for 3h. The crucible with the ashed sample was then cooled in a desiccator and reweighed (W3). Ash content was calculated using the expression:

$$\% \, Ash = \frac{W2 - W1}{W2} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

2.1.3 Determination of crude protein content

Determination of crude protein was done according to AOAC (2000), method 984.13 whereby 2g of uncooked and cooked ground bean grains from each variety was mixed with 20 ml of concentrated sulphuric acid in a clean well-labelled digestion tube. Kjeldahl tablets (catalyst) were added to the mixture (selenium powder and concentrated sulphuric acid (2.8 g/800-mL), in the tube and the sample was digested in a Gerhardt Kjeldahl thermo digester (Model: KB40; Gerhardt GMBH and CO. Kg; Germany) for 1hr at 420˚C. Distilled water was added to the digest to make an 80 ml volume. Exactly 50 ml of sodium hydroxide solution was then added to the mixture and followed by distillation of the ammonia into concentrated boric acid using a 2200 Kjeltec TM auto distillation unit (Foss Analytical, Höganäs, Sweden). Titration was done using hydrochloric acid (0.1mol/L) after adding a few droplets of indicator solution. Nitrogen content (g/100g) was obtained using the formula;

$$N(g/100g) = (Vs - Vb) \times M(HCL) \times 1 \times 14.007/W \times 10$$

Where: Vs is the volume of HCl (ml) needed to titrate the sample; Vb is the volume of HCl (ml) needed to titrate the blank test; M (HCl) is the molarity of hydrochloric acid; the numeral one (1)

is the acid factor; 14.007 is the molecular weight of nitrogen; W is the weight of the sample (g) and 10 is the conversion factor from mg/g to g/100g. Crude protein content was obtained by multiplying the nitrogen content by 6.25.

2.1.4 Determination of crude fat content

Crude fat extraction was done according to AOAC (2000), method 920.39. About 5g of the uncooked and cooked ground bean grains from each variety was weighed (W1) into the extraction thimble and covered with a fat-free clean wad of cotton wool. The thimble was then fitted to a clean dry round bottom flask that had been cleaned, dried, and weighed (W2). Exactly 25 mL of petroleum ether was added to the extraction flask. The Electro-thermal Soxhlet-Apparatus (Model: EME 6250/CF; Cole Parmer; England) was set to extract the sample for 6 hrs. after which the solvent was evaporated, flask dried in a desiccator and reweighed (W3). Crude fat content (%) was calculated using the formula:

$$\%\ Crude\ fat\ content = 100 \times \frac{(W3-W2)}{W1} \ldots\ldots 4$$

W1 is the initial sample weight in grams, W2 is the tare weight of the flask in grams, and W3 is the weight of the flask and fat residue in grams.

2.1.5 Determination of crude fibre

Crude fibre was determined according to AACC (2000), method 6865. A sample of 2 g of raw and cooked ground bean grains of each variety was extracted with ether to remove fat. After extraction 2g of this sample was boiled with 200 ml of sulphuric acid for 30min, then filtered through a muslin cloth and was washed with boiling water until no longer acidic, then boiled with 200 ml Sodium hydroxide for 30 min, filtered through a muslin cloth and was then washed with 25 ml of boiling 1.25% Sulphuric acid, 3.50 ml portions of water and 25 ml alcohol and all this was done in a Fibretec digester (FOSS, Sweden). The residue was removed and transferred to the ashing dish (pre-weighed dish—W1). The residue was dried for 2hrs at 130˚C ± 2˚C and cooled in a desiccator and weighed (W2). Then ignited for 30min @600˚C in a muffle furnace (Model: MR170; S/N: 6800616; Hereaus GMBH, Hanau, Germany) then cooled in the desiccator and reweighed (W3). The formula to be used;

$$\%\ Crude\ fibre = \frac{(W2-W1)-(W3-W1)}{Weight\ of\ sample} \times 100 \ldots\ldots 5$$

2.1.6 Carbohydrate content determination

Carbohydrate content was calculated by the difference method using the following equation:

$$\%\ carbohydtare = 100\ \% - (\text{Moisture} + \text{Crude fat} + \text{Ash} + \text{crude protein}) \ldots\ldots 6$$

2.1.7 Minerals analyses

Mineral determination was done using the AOAC (2000), method 985.35. Exactly 5mls of Conc. HNO_3 and 1 ml Conc. $HClO_4$ was used to digest 1g raw and cooked ground bean grains of each variety. Allowed to stand closed overnight at room temperature to predigest the sample and thereafter placed in an oven at 100˚C for 8hrs and cooled to room temperature in a fume hood. Atomic absorption spectrophotometer Thermo Jarrell Ash Corporation (model 6) was used for the analysis of Calcium, Magnesium, Zinc, Sodium, and Phosphorus. UV/visible spectrophotometer (JENWAY 7315) was used for phosphorus, calcium, potassium, magnesium, sodium, zinc, and

iron, and measured at wavelengths of 422.7, 766.5, 285.2, 589.0, 213.9, 510, and 880 nm respectively. A flame spectrophotometer (Flame photometer model 410, United Kingdom) was used for potassium.

2.2 Antinutrient analyses

2.2.1 Determination of total phenolic content

Total phenolic content of the uncooked and cooked ground bean grains of each variety were analyzed using the Folin-Ciocalteu method (Singleton & Rossi, 1965) and as modified by (Siwela et al. (2007) A weight of 300 mg of this sample was extracted with 30ml of acidified methanol for 1hr at room temperature and then centrifuged at 2060 ×*g* for 20min using Eppendorf centrifuge (Model 5804, Eppendorf, Hamburg, Germany), decanted and three replicate supernatants obtained. Sample extracts (0.5-ml) were mixed with 2.5-ml of Folin-Ciocalteu phenol reagent in a 50-ml centrifuge tube containing 10ml distilled water, 7.5-mL of 20% (w/v). Sodium carbonate was added within 8 min after adding the Folin-Ciocalteu reagent. The contents were then made up to volume with distilled water, Stoppard, and then thoroughly mixed. Tubes were left to stand at room temperature for 2hrs and absorbance was read at 760 nm using a UV/VIS Spectrophotometer (model PharmaspecUV-27 1700, Shimadzu, Japan). Sample blank was included in which distilled water replaced the sample. Tannic acid was used as standard and total phenolics were expressed as mg Tannic Acid Equivalent per gram of sample (mg TAE/g).

2.2.2 Determination of phytic acid content

Phytic acid analysis was based on phytate precipitation, as described by Makkar *et al*. (2007). Raw and cooked bean ground samples (500 mg) of each variety were accurately weighed and phytate was extracted using 50ml of 3% trichloroacetic acid (TCA) by shaking on Ratek Orbital Incubator (Boronia, Victoria, Australia) for 40min. The suspension was then centrifuged at (3000 ×*g*, 10 min) using an Eppendorf centrifuge (Model 5804, Eppendorf, and Hamburg, Germany), a 10-ml aliquot of the supernatant was transferred to a 50-ml centrifuge tube and 4 ml of $FeCl_3$ solution added rapidly. The contents in the tubes were then heated in boiling water for 45min, then centrifuged at 3000×*g* for 10min using an Eppendorf centrifuge (Model 5804, Eppendorf, Hamburg, Germany) and the clear supernatant was decanted. The precipitate was then washed twice by dispersing in 25-mL 3% TCA, and then heated in boiling water for 10 min, then centrifuged at (3000 ×*g*, 10 min) using Eppendorf centrifuge (Model 5804, Eppendorf, Hamburg, Germany), and then washed again with 20-ml distilled water. The precipitate was then dispersed in 5ml of distilled water and 3ml of 1.5N NaOH added, and then topped up 30ml with distilled water and S for 30 min in boiling water. The contents were then filtered using Whatman No. 2 filter paper with a pore size of 8µm and then washed with 70-ml hot distilled water. The precipitate was transferred and dissolved into the 100-ml volumetric flask containing 40-ml hot 3.2N HNO_3. The filter paper was washed using distilled water, and the washings were collected in the same flask. The flask was cooled to room temperature and the volume made to 100-mL with distilled water. An aliquot (5-ml) was transferred to another 100-mL volumetric flask and mixed with 65-mL distilled water, 20-mL 1.5M potassium thiocyanate (KSCN) then added. The volume was added to 100 mL with distilled water, and the colour read at 480 nm using a spectrophotometer (model pharmaspec UV-1700 Shimadzu, Japan) within I minute. Reagent blank in which distilled water would replace the sample was included. A calibration curve was made from iron (III) nitrate solution stock solution. Iron (in micrograms), present in the test solution was determined from the calibration curve and phytate P calculated as follows:

$$Phytate\ P\ mg/g = \frac{\text{Fe (µg)} \times 15}{\text{Weight of sample (g)}} \quad \ldots\ldots 7$$

2.2.3 Determination of condensed tannin content

Modified vanillin-HCl in the methanol method was used in determining condensed tannins as described by Price et al. (1978). Uncooked and cooked ground bean grains (0.25g) of each variety was weighed into a 100-mL conical flask, and then 10-mL 4% HCl in methanol (v/v) was added and the content shook for 20 min using Ratek Orbital Incubator (Boronia, Victoria, Australia). This mixture was then centrifuged at 2060 $\times g$ for 20 min at room temperature using Eppendorf centrifuge (Model 5804, Eppendorf, Hamburg, Germany). Sample extracts (1-ml) were then mixed with 5-ml of the vanillin-HCl reagent in a clean test tube. The specific reagent (vanillin-HCl) for the determination was prepared just before use by mixing equal volumes of 1% vanillin in methanol (w/v) and 8% conc. HCl in methanol (v/v). Absorbance was read at 500 nm using UV/VIS Spectrophotometer (model Pharmaspec UV-1700 Shimadzu, Japan) exactly after 20 min. Sample blanks in which 4% HCl in methanol replaced vanillin reagent was included. For the zero setting of the colorimeter, 1-ml of a blank (1% HCl in methanol was used. Catechin was used as a standard. Condensed tannin was expressed as mg catechin equivalent per gram of sample (mg CE/g).

2.4 Statistical analysis

Data on proximate, mineral and ant-nutrient composition of both raw and cooked bean varieties were evaluated using SAS® software version. ANOVA was performed to test the study hypotheses; t-test was performed to determine the effect of cooking for each variety and multinomial logistic regression was done to compare the effect of cooking for each variety to the reference variety in SAS software using the PROC GLM, PROC TTEST and PROC LOGISTICS procedures, respectively. Correlation analysis to establish the relationship between proximate and anti-nutrients in cooking was performed using PROC CORR. Data were analysed at a 95% confidence level, and post-hoc analysis was performed using Tukey's honestly significant difference (HSD). Data output is presented in the form of tables and graphs.

2.5 RESULTS AND DISCUSSION

The common bean is considered a perfect food due to its high content of fibre, protein, antioxidant capacity and many bioactive compounds (OECD, 2015). The high amounts of these beneficial health compounds have further been attributed to the prevention of various diseases including diabetes, oxidative stress, intestinal inflammation, and cardiovascular diseases (Câmara *et al*., 2013; Hayat *et al*., 2014).

There was a significant variation in the ash, protein, crude fibre, crude fat, carbohydrate, condensed tannins, phytic acid, and total phenolics across the common bean varieties ($P<0.05$) (Figure i).

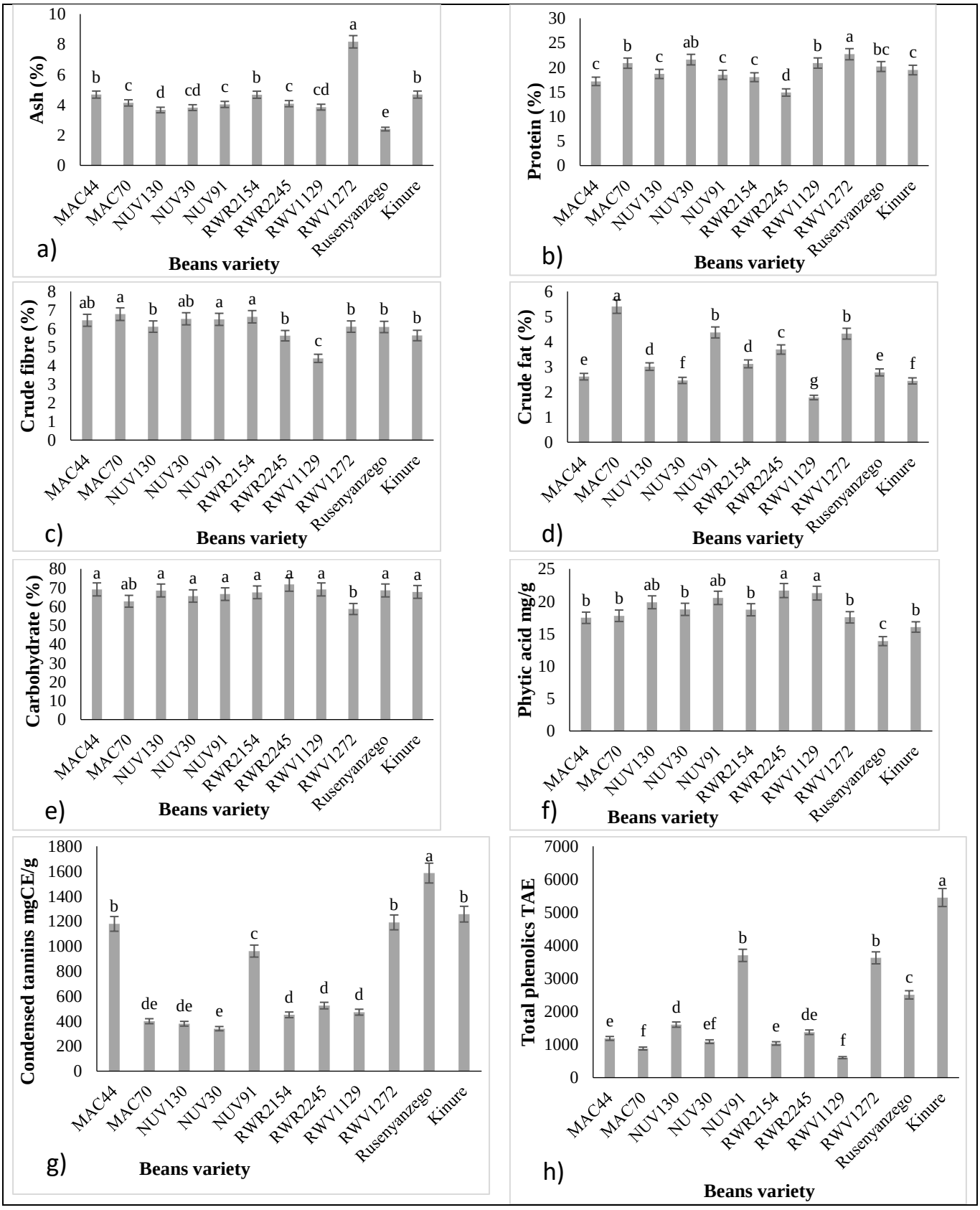
a)
Ash (%)
Beans variety
b)
Protein (%)
Beans variety
c)
Crude fibre (%)
Beans variety
d)
Crude fat (%)
Beans variety
e)
Carbohydrate (%)
Beans variety
f)
Phytic acid mg/g
Beans variety
g)
Condensed tannins mgCE/g
Beans variety
h)
Total phenolics TAE
Beans variety
MAC44
MAC70
NUV130
NUV30
NUV91
RWR2154
RWR2245
RWV1129
RWV1272
Rusenyanzego
Kinure

Figure i: Proximate and anti-nutrient composition in different raw biofortified and non-biofortified common bean varieties. Different letters along the bar graphs are significantly different ($p< 0.05$). Values for crude fibre, protein, and fat are expressed in (g/100g), phytic acid in mg/g, condensed tannins in mgCE/g, total phenolics in TAE and carbohydrates in %.

2.5.1 Proximate analyses

a) Ash content

The range of the ash content in biofortified beans was 3.66g-8.17/100g while non-biofortified beans had an ash content of 2.4 and 4.68g/100g in *Kinure* and *Rusenyanzego* respectively (Figure i (a)). The RWV1272 variety had the highest ash content of 8.17 g/100g while NUV130 had the lowest ash content of 3.66 g/100g. These results are higher compared to those of biofortified common beans grown in Brazil with an ash content ranging from 4.1 to 4.57% (Brigide et al., 2014a). Results from a recent study by Mananga et al. (2022), indicated a mean ash content of 4.33% in FEB 192, a biofortified bean variety grown in the West region of Cameroon. We argue that the differences in the ash content in these studies could be attributed to geographical cultivation conditions. MAC44, RWR2154 and *Kinure* had no significant difference ($p> 0.05$) in the ash content. Additionally, there was no significant difference in the ash content of MAC70, NUV30, NUV91, RWR2245 and RWV1129 ($p> 0.05$). The close proximity in the ash content in these varieties could be as a result of the biofortification process while the differences could be attributed to the cultivation environment.

b) Crude protein content

The protein ranged from 14.89 g/100g to 22.69 g/100g (Figure i (b)). There was no significant difference in the protein content of varieties RWV1272 and NUV130. According to Esteves et al. (2002), the protein content of beans on a dry basis is between 22% and 26%, values in close proximity to the current study. Other studies have also reported similar crude protein results in raw common bean and improved cowpea lines legumes (Biama *et al*., 2020; Brigide *et al*., 2014; Carbas *et al*., 2020; Carvalho *et al*., 2012; Nwadike *et al*., 2018; Palacio-Márquez *et al*., 2021). The varying contents of protein in the varieties may be due to genetic and climatic parameters; including temperature and rainfall (Carbas *et al*., 2020). Protein provided by beans is an important nutrient to meet the nutritional requirements of the Burundian population.

c) Crude fibre

The range of the fibre content was 4.40-6.78g/100g in biofortified varieties while 5.63-6.09g/100g in traditional varieties (Figure i (c)). There were no significant differences in the fibre content of varieties MAC44, MAC70, NUV30, NUV91, and RWR2154 and also in the traditional varieties ($p> 0.05$). RWV1129 bean variety recorded the lowest crude fibre content of 4.40 g/100g. Common beans contain considerable amounts of dietary fibre in the form of hemicellulose, cellulose, pectins, lignin, and oligosaccharides (Nwadike *et al*., 2018). They are absorbed in the small intestine and then partially or completely fermented in the large intestine imparting various physiological impacts on the human body. Fibre is valuable in managing different diseases as it helps control slow carbohydrate release during digestion (Hayat *et al*., 2014). According to (Messina, 2014), crude fibre in common beans varies from 14g to19g per 100g with the potential of reaching 50% soluble fibre and hence a possible reduction in blood cholesterol levels.

d) Crude fat

Compared to the content of other macronutrients, lipid content is generally low in the common beans (Hayat *et al*., 2014). The lipid content of biofortified bean varieties was higher compared to the fat content of traditional varieties (Figure i (d)). MAC70 had the highest amount of crude fat (5.4 g/100g) which was significantly different ($p< 0.05$) from other bean varieties. Mananga *et al*. (2022) reported similar results in raw FEB 192, a biofortified common bean variety, cultivated in Cameroon. The fat content of *Kinure* and *Rusenyanzego* was 2.44 and 2.48 g/100g respectively, amounts not significantly different from those of MAC44 and NUV30 biofortified varieties. There was no significant difference between NUV91 and RWV1272 varieties in the crude fat content. RWV1129 had the lowest fat content of 1.78 g/100g. Hayat *et al*. (2014) reported that common bean varieties are essential sources of unsaturated fatty acids, containing about 61% of the total fatty acids with linoleic, oleic, and palmitic acids being dominant. Linolenic acid is the most dominant unsaturated fatty acid in beans containing up to 43.1% of the fatty acids (Hayat *et al*., 2014).

e) Carbohydrate content

The carbohydrate content was highest in the RWR2245 bean variety at 71.7% while lowest in the RWV1272 variety (58.7%) (Figure i (e)). These results were higher than findings reported by Brigide *et al*. (2014)**,** which revealed a carbohydrate content ranging from 16.18 to 22.68% in raw biofortified beans grown in Brazil. Furthermore, results from a study by Mananga *et al*. (2022), reported a mean carbohydrate content of 57.79%. Additionally, there were no significant differences in the carbohydrate content among the bean varieties except for RWV1272 ($p>0.05$). This means that the other varieties had similar carbohydrate content. The major component of common bean varieties is carbohydrates, accounting for 50-60% of dry matter (Ovando-Martínez *et al*., 2011). Non-starch polysaccharides and starch form the major carbohydrate components together with other derivatives such as oligosaccharides.

2.5.2 Antinutrient composition

a) Phytic acid

There was no significant difference among the phytic acid contents of NUV130, NUV91, RWR2245, and RWV1129 bean varieties at 19.85, 20.53, 21.66 and 21.26 mg/g respectively (Figure i (f)). *Rusenyanzego* and *Kinure* traditional varieties had phytic acid at 13.86 mg/g and 16.04 mg/g. These results fall in the range registered in a study by Hummel *et al*. (2020) with an average phytic acid content of 18.62mg/g in raw biofortified bean varieties grown in n Valle del Cauca, Colombia. Furthermore, the phytic acid content of conventional bean varieties in that study were lower compared to the content of biofortified bean varieties, findings similar to the current study. Increased iron content is correlated with an increased phytic acid content and the varieties utilised in the current study are characterised as having high iron and zinc content resulting from the biofortification process (Hoppler, 2014). Phytate impair the absorption of Ca, Fe and Zn thus affecting their bioavailability to humans. However, although phytate have been scientifically proven to impair the absorption of Ca, Fe and Zn thus affecting their bioavailability in humans, phytate are associated with health benefits. Thus, there is a need to conduct extensive health studies before a cultivar is chosen for food production applications (Celmeli *et al*., 2018).

b) Condensed tannins

Traditional varieties *Rusenyanzego* and *Kinure* had a higher concentration of condensed tannins at 1585.47 and 1256.9 mgCE/g respectively, unlike the biofortified bean varieties with a range of 340.35-1190.90mgCE/g of condensed tannins (Figure i (g)). TheNUV30 variety had the least amounts at 340.25 mgCE/g. However, there was no significant difference in the quantities of *Kinure*, RWV1272 and MAC44 varieties. Tannins affect digestibility and bioavailability of nutrients (Carbas *et al*., 2020).

c) Total phenolics

The total phenolic content in biofortified common beans ranged from 605.32-3624.88 TAE while that of *Kinure* and *Rusenyanzego* was recorded as 5449.47 and 2504.87 TAE respectively (Figure i (h)). Variety RWV1129 had the lowest total phenolic content (605.32 TAE). Total phenolic content in varieties RWV1272 (36.24.88 TAE) and NUV91 (3699.17 TAE) was not significantly different ($p > 0.05$). The phenolic compounds in beans majorly include flavonoids such as proanthocyanidins anthocyanins, phenolic acids and flavanol. Proanthocyanidins can be found in almost all varieties of beans (Akond *et al*., 2011). The phenolic components are majorly located in the seed coat with small amounts found in the cotyledon. Both environmental and genetic factors influence total phenolics levels in the bean varieties and affect seed coat colour due to flavonoid composition variability (Ovando-Martínez *et al*., 2011). Consuming common beans is beneficial due to the functional and nutraceutical potential of phenols which exhibit both anticarcinogenic and antioxidant properties (Hayat *et al*., 2014). A study by Akond *et al*. (2011) recorded variations in different varieties of common beans with total phenolic contents ranging between 5.87 mg/100g and 14.14 mg/100g.

2.6. Effect of cooking on proximate components of different bio-fortified bean varieties

a) Ash content

The ash content of *Kinure*, NUV130, NUV30, NUV91 and *Rusenyanzego* increased after cooking (Table I). However, there was a decrease in the ash content of MAC44, MAC70, RWR2154, RWR2245, RWV1129 and RWV1272 varieties. The observed decrease may have resulted from certain minerals' diffusion into the beans cooking water. Wang *et al*. 2010 reported similar results for common beans and chickpeas. Jayalaxmi *et al*. (2015) and Saulawa *et al*. (2014) associated ash content reduction during thermal processing with the leaching of both micro and macro elements into the broth.

b) Protein content

Cooking increased the protein content in both traditional varieties (*Rusenyanzego and Kinure)* and biofortified varieties *(*NUV30, NUV91, RWV1129) but decreased that of MAC44, MAC70, RWR2154, RWR2245, NUV130 and RWV1272 biofortified bean varieties (Table 4.1). Variety RWR1272 (21.87g/100g) and RWR2245 (10.86g/100g) had the highest and lowest protein content sequentially. Mananga *et al*. (2022), reported an increase in protein content in both cooked and non-biofortified varieties grown in Cameroon. Most forms of bean processing methods can enhance crude protein content through changes in the association and dissociation properties of proteins caused by heating. For instance**,** Farinde *et al*. 2018**,** reported that fermentation and germination had a minimum reduction in the protein content of common beans grown in Nigeria by 2.56% and 5.35% respectively. The increase in the protein content in the fermented beans was attributed to microbial activities during the fermentation process. The microorganisms must have

probably synthesized proteinase enzymes, which hydrolyzed the complex plant protein to amino acids and peptides resulting in an increase in the total nitrogen (Farinde *et al*., 2017).

Table I Nutritional composition of biofortified and traditional common bean varieties

Values are mean ± standard deviations. Values along the column followed by different

Variety	State	Ash	Protein	Fibre	Fat	CHO
Kinure	Raw	4.68±0.07^{b}	19.47±0.19^{a}	5.63±0.05^{b}	2.44±0.02^{b}	67.78±0.33^{a}
	Cooked	5.46±0.10^{a}	20.20±0.20^{a}	11.42±0.20^{a}	4.13±0.09^{a}	58.79±0.59^{b}
MAC44	Raw	4.68±0.01^{a}	17.16±0.34^{a}	6.45±0.02^{b}	2.61±0.03^{b}	69.11±0.36^{a}
	Cooked	2.62±0.04^{b}	13.97±0.05^{b}	11.06±0.05^{a}	5.37±0.12^{a}	66.98±0.15^{b}
MAC70	Raw	4.13±0.07^{a}	20.87±0.15^{a}	6.78±0.09^{b}	5.40±0.04^{a}	62.81±0.33^{a}
	Cooked	4.02±0.03^{a}	18.75±1.07^{a}	13.29±0.09^{a}	8.52±0.09^{a}	55.42±1.20^{b}
NUV130	Raw	3.66±0.03^{a}	18.67±0.09^{a}	6.11±0.02^{b}	3.01±0.06^{b}	68.54±0.17^{a}
	Cooked	3.67±0.03^{a}	18.35±0.12^{a}	8.27±0.02^{a}	3.69±0.04^{a}	66.02±0.16^{b}
NUV30	Raw	3.82±0.03^{a}	21.59±0.13^{a}	6.53±0.03^{b}	2.46±0.01^{b}	65.60±0.16^{a}
	Cooked	3.97±0.05^{a}	21.65±0.33^{a}	11.20±0.19^{a}	5.71±0.08^{a}	57.48±0.65^{b}
NUV91	Raw	4.03±0.08^{b}	18.49±0.07^{b}	6.50±0.04^{b}	4.37±0.09^{a}	66.61±0.27^{a}
	Cooked	4.39±0.04^{a}	19.40±0.12^{a}	13.33±0.03^{a}	2.13±0.01^{b}	60.75±0.15^{b}
RWR2154	Raw	4.67±0.01^{a}	18.01±0.08^{a}	6.64±0.05^{b}	3.12±0.03^{b}	67.56±0.16^{a}
	Cooked	3.79±0.07^{b}	16.58±0.23^{b}	10.18±0.03^{a}	4.33±0.03^{a}	65.12±0.33^{b}
RWR2245	Raw	4.08±0.31^{a}	14.89±0.06^{a}	5.62±0.04^{b}	3.69±0.05^{b}	71.72±0.33^{b}
	Cooked	3.17±0.02^{b}	10.86±0.04^{b}	7.24±0.02^{a}	4.69±0.01^{a}	74.05±0.06^{a}
RWV1129	Raw	3.85±0.06^{a}	20.89±0.21^{a}	4.40±0.03^{b}	1.78±0.01^{b}	69.09±0.27^{a}
	Cooked	3.43±0.03^{b}	21.24±0.15^{a}	8.83±0.05^{a}	5.36±0.05^{a}	61.14±0.22^{b}
RWV1272	Raw	8.17±0.05^{a}	22.69±0.17^{a}	6.11±0.02^{b}	4.32±0.10^{a}	58.70±0.25^{b}
	Cooked	4.12±0.01^{b}	21.87±0.06^{b}	8.95±0.04^{a}	4.59±0.07^{a}	60.46±0.04^{a}
Rusenyanzego	Raw	2.40±0.03^{b}	20.18±0.14^{b}	6.09±0.05^{b}	2.78±0.04^{b}	68.56±0.24^{a}
	Cooked	3.96±0.04^{a}	22.69±0.17^{a}	10.86±0.02^{a}	5.47±0.03^{a}	57.44±0.07^{b}

Superscript letter notations are significantly different (P<0.05). CHO-Carbohydrates

The cooking process also disintegrates the crude protein into amino acids inducing changes in the structure of the proteins, which can inactivate the antinutrient (Farinde *et al*., 2018). Consequently, the process increases the digestibility and the biological values of the protein in the beans (Audu & Aremu, 2011; Fernandes *et al*., 2010)**.** The increase in proteins in the cooked bean varieties can be a result of the loss of soluble solids that increased protein concentration in the cooked beans (Wang *et al*., 2010). The decrease of proteins in the other varieties could be attributed to soluble proteins diffusing into the cooking water.

According to Messina (2014), cooked dry beans are rich in protein, providing 20% to 30% of calories derived from proteins. A serving of beans (~90 g or 0.5 cup cooked beans) contains about 7 to 8 g proteins and provides three times as much protein unlike a comparable serving of maize

(*Zea mays* L.). However, it is not the protein content that is unique to dry-cooked beans but the lysine content. Lysine is an essential amino acid that may be deficient in plant-based diets such as legume source (soy or peanut). One serving of half a cup of cooked dry beans provides only 16% of the total protein requirement for a 60-kg person, but 25% of the total lysine requirement, making cooked beans ideal for people on plant-based diets. Cooked beans, therefore, complement other cereals such as wheat and maize, which are deficient in lysine (Słupski, 2010). This complementary strategy is considered the best intervention for alleviating protein-energy malnutrition as it promotes a balanced diet (Batista *et al*., 2010). Based on this study, varieties MAC70, NUV130, NUV30, RWV1129 and RWV1272 are the best protein sources and could be promoted for consumption in the alleviation of protein-energy malnutrition among malnourished children and the general population. These varieties could also be explored in the formulation of infant foods.

c) Crude fibre content

The fibre content of both traditional and bio-fortified bean varieties increased after cooking (Table I). Traditional varieties had a higher fibre content ranging from 10.86-11.42g/100g, unlike the biofortified varieties with a range of 6.45-13.33g/100g. Mananga *et al*. (2022), reported similar results in Cameron whereas Farinde *et al*. (2018), reported results contrary to those reported in this study whereby the fibre content of lima beans grown in Nigeria decreased after processing (germination, fermentation and roasting). We contend that the discrepancies are due to the different processing treatments in these studies. The values in this study were within the range of 4.5%-17.5% reported by Messina (2014) and less than 17.41 % -28.20% (OECD, 2015) for different bean cultivars in America and Paris respectively. The high rate of crude fibre in the processed samples could be explained by the fact that heat treatments can have variable effects on crude fibre causing disruption of the cellular components of beans (cellulose, hemicelluloses, lignin, pectin and gums). Consequently, the cooking process results in interactions between proteins and lipids leading to qualitative and quantitative changes in the composition of the total fibre of cooked beans compared to that of raw beans (Brigide *et al*., 2014). The fibre content of all the biofortified common bean varieties utilized in this study is within the recommended range. These varieties can be promoted for consumption to contribute to a healthy gastrointestinal tract and other health benefits associated with high-fibre consumption. Additionally, other processing methods such as fermentation can be explored to benefit more from these varieties.

d) Crude fat content

Cooking increased the fat content of all bean varieties except for NUV91 which recorded a reduction (Table I) an observation similar to Brazilian biofortified beans (Brigide *et al*., 2014). However, results from a study by Mananga *et al*. (2022)reported a decrease in fat content in a biofortified common variety FEB 192 after boiling. Among the cooked dry biofortified common bean varieties, variety MAC70 (8.52g/100g) had the highest fat content while variety NUV91 (2.13g/100g) had the lowest fat content. Dry-cooked beans are not only a unique source of proteins but also an excellent plant-based diet with low-fat content ideal for weight management (Hayat *et al*., 2014). Approximately 3% of kilocalories in beans are derived from fat, most of which is unsaturated. However, chickpeas provide approximately 15% of kilocalories derived from fat (Messina, 2014). The loss of fat in the NUV91 bean variety could be as a result from fat leaching with cooking water during the boiling process. The variation in the fat content could be attributable to varietal disparities, cultivation areas and agronomic practices.

e) Carbohydrate content

There was a significant reduction in carbohydrate content in all bio-fortified bean varieties after cooking except for the RWR2245 variety. Traditional varieties had a range of 57.44-58.79 % while biofortified had a range of 55.42-74.05%. These results were in close proximity to those reported by (Mananga *et al*., 2022), for a biofortified bean variety FEB 192 and a traditional variety PH 201 grown in Cameroon. However, a similar trend (decrease in carbohydrate content after cooking) has been reported in white beans, brown beans and in processed velvet beans grown in Nigeria (Alayande, 2012; Bamigboye & Adepoju, 2015). According to Farinde *et al*. (2018), the decrease in carbohydrate content after cooking results from the fact that carbohydrates are water-soluble, therefore easily hydrolysable and diffuse in soaking and cooking water. Furthermore, during wet heat treatment such as boiling, low molecular weight carbohydrates (mono and disaccharides) are considerably lost in the broth causing a significant decrease in carbohydrate content (Bamigboye & Adepoju, 2015). The carbohydrate content of the varieties utilised in this study suggests that these varieties can be used in feed formulations and among the diabetic population in Burundi.

2.7 Effect of cooking on anti-nutrient components of different bio-fortified bean varieties

a) Phytic acid

Cooking affected phytic acid concentration both negatively and positively. A significant reduction in phytic acid concentration was observed in *Kinure*, NUV130, NUV3, RWR2245 and RWV1129 varieties while there was an increase in phytic acid levels in MAC44, RWV1272 and *Rusenyanzego* varieties (Table I). Cooking had no significant effect on the phytic acid level in the NUV91, RWR2154 and MAC70 bean varieties. RWR2245 (14.25mg/g) had the least concentration of phytic acid after cooking. According to Fabbri and Crosby, (2016), boiling reduces the phytate content of vegetables. On the other hand, phytate are heat stable and therefore less affected by boiling. However, prolonged cooking can cause a detrimental reduction in the phytic acid concentration. This phenomenon could explain why boiling affected phytic acid concentration in both directions (increment and reduction). We however argue that dry bean grains are cot categorised as vegetables. Phytate are known to have antinutritional effects through the formation of insoluble complexes with proteins, essential minerals and amides. These complexes consequently inhibit the enzymatic digestion of protein and lower the bioavailability of minerals such as K and Zn and also, phytate phosphorous becomes unavailable to human consumers (Hummel *et al*., 2020; Silva *et al*., 2017). Mananga *et al*. (2022b) reported that soaking red and white biofortified beans with *Echinops giganteu*s bark powder and soaking with sodium bicarbonate powder and boiling significantly reduced ($p<0.05$) all the phytate evaluated beans. Such pre-treatment methods can be further explored using biofortified varieties utilised in this study.

Table II. Effect of cooking on proximate components of different biofortified and traditional bean varieties

Variety	State	PA	TP	CT
Kinure	Raw	16.04±0.25[b]	5449.70±53.46[a]	1256.90±12.62[a]
	Cooked	20.32±0.32[a]	4073.89±65.47[b]	344.65±5.21[b]
MAC44	Raw	17.46±0.27[b]	1186.91±6.10[a]	1178.93±6.48[a]
	Cooked	19.00±0.16[a]	785.60±3.54[b]	359.02±1.66[b]
MAC70	Raw	17.77±0.19[a]	881.42±7.70[a]	399.97±3.51[a]
	Cooked	17.92±0.21[a]	549.53±4.36[b]	376.44±3.32[a]
NUV130	Raw	19.85±0.14[a]	1605.58±7.53[a]	379.63±1.82[a]
	Cooked	17.73±0.20[b]	1025.56±2.55[b]	299.36±0.51[b]
NUV30	Raw	18.76±0.09[b]	1089.45±5.27[b]	340.25±1.40[a]
	Cooked	20.11±0.22[a]	1401.92±16.69[a]	196.06±2.60[b]
NUV91	Raw	20.53±0.06[a]	3699.17±14.25[a]	961.27±3.67[a]
	Cooked	20.53±0.30[a]	974.63±1.94[b]	156.86±0.27[b]
RWR2154	Raw	18.70±0.11[a]	1034.39±4.17[b]	450.96±2.20[a]
	Cooked	18.31±0.12[a]	1501.89±9.68[a]	270.41±1.48[b]
RWR2245	Raw	21.66±0.18[a]	1373.81±5.29[a]	524.97±2.06[a]
	Cooked	14.75±0.22[b]	927.50±2.17[b]	454.39±1.47[b]
RWV1129	Raw	21.26±0.17[a]	605.32±4.66[b]	472.24±3.47[a]
	Cooked	17.41±0.05[b]	833.77±2.26[a]	353.71±0.89[b]
RWV1272	Raw	17.53±0.25[b]	3624.88±22.34[a]	1190.90±7.30[a]
	Cooked	18.81±0.11[a]	1316.08±2.71[b]	159.54±0.75[b]
Rusenyanzego	Raw	13.86±0.12[b]	2504.87±90.84[a]	1585.47±11.81[a]
	Cooked	20.02±0.03[a]	1336.50±1.89[b]	211.77±0.38[b]

PA= phytic acid(mg/g); CT= condensed tannins (mgCE/g); TP= total phenolics (TAE). Values are mean ± standard deviations. Values along the column followed by different superscript letter notations are significantly different (P<0.05)

b) Condensed tannins

Cooking significantly reduced ($P<0.05$) the condensed tannins content in both biofortified and traditional bean varieties (Table II). The condensed tannins in traditional varieties ranged from 211.038-344.65mgCE/g while biofortified beans showed a range of 156.86-454.39 mgCE/g. Mananga *et al*. (2022b) also reported a reduction in the tanning content of both traditional and biofortified processed common bean varieties. Other researchers previously reported a reduction in the tannin content in cooked common beans (Mugabo *et al*., 2017; Silva *et al*., 2017). The reduction is quite desirable since they are primarily considered to be an antinutritional factor. High concentration of tannins has been affirmed to be detrimental to iron absorption (Petry *et al*., 2015). These has led to a majority of populations in countries such as Burundi to suffer from iron deficiency and its related health complication despite consuming biofortified bean varieties that are high in this mineral in the country. Tannin is reported to be concentrated in the seed coat and soaking and cooking are processing methods that can reduce the concentration of tannins (Mananga *et al*., 2022b). Furthermore, tannins are polyphenols and polyphenolic compounds are mostly water-soluble in nature (Ojo, 2022).

The reduction of tannins after soaking and boiling is therefore due to the leaching of polyphenols in the soaking water as soaking acted as a pre-treatment before cooking (Ojo, 2022). In addition, Silva *et al*., (2017), explained that the reduction caused by soaking and cooking did not result from the chemical destruction of tannins, but was due to modifications in the solubility and reactivity characteristics of other food molecules. Mariotto-Cezar *et al*. (2013), researched various domestic processing methods for common bean consumption and concluded that soaking and boiling without the soaking water is the most effective method to reduce tannin concentration and consequently tannin intake. De Toledo *et al*. (2013) reported that tannins have the potential to bind with proteins hindering their absorption and bean digestibility, and hence reducing phaseolin hydrolysis. A comprehensive review of the impact of the consumption of tannins in human and animal diets has recently been discussed by Ojo (2022).

b) Total phenolics

There was a reduction in total phenolics content in all biofortified bean varieties except for NUV30, RWR2154 and RWV1129 bean varieties (Table II). Phenolic compounds are found covalently bonded to amine functional groups. Cooking likely hydrolyses these compounds thus affecting their aromatic rings making them more susceptible to decomposition and polymerisation (Granito *et al*., 2007). Similar studies have reported a significant decrease in total phenolics after subjecting raw *Vicia faba L.* variety to cooking (Siah *et al*., 2014; Eshraq *et al*., 2016). The decrease may be the effect of cooking that released low molecular phenolic compounds as the antioxidant capacity increases (Silva *et al*., 2017). According to Huang & Xu (2021) and Mileo & Miccadei (2016), temperature and time affect the stability of total phenolic compounds thus the need for monitoring especially if the goal is to preserve their concentration. This concept could be a probable explanation for the reduced concentration in the phenolic content of varieties NUV130, RWR2245, MAC70, MAC44, RWR1272, NUV91 and the traditional varieties *Kinure* and *Rusenyanzego*. We can also infer that phenolics content were more stable in varieties NUV30, RWR2154 and RWV1129. Total phenolics are associated with beneficial health outcomes such as the prevention of atherosclerosis, antihypertensive and anticancer activity (Huang & Xu, 2021; Mileo & Miccadei, 2016).

2.8 Effect of cooking on the mineral content of the various common bean varieties

Analysis of Variance showed that cooking significantly affected the mineral elements found in different common bean varieties (Table III). NUV130 was highest in both Fe (115.7 mg/100g) which is present in non-heme form and Zn (53.6 mg/100g), MAC44 in Ca (1166.8 mg/100g), NUV91 in Mg (1586 mg/100g), Kinure in P (304.7 mg/100g), RWV1272 in both K (1266.1 mg/100g) and Na (800 mg/100g). Cooking contributed to considerable losses of Fe element in RWR2154 (9.3%), NUV130 (71.3%), MAC70 (27.1%) and RWV1272 (26.7%) bio-fortified bean varieties. Cooking however increased the Fe level in the RWV1129 variety by 68%. The Zn content increased significantly in all bean varieties except MAC70 which reduced by 12.4%. Ca content greatly decreased in NUV130, RWV1272 and MAC44 by 28.2%, 15.8% and 3.1% respectively, compared to the remaining varieties.

Results from Table III also showed that Mg was the most abundant element in the cooked common beans ranging from 1538 to 2045.2 mg/100g while Zn was the least abundant ranging from 20.34 to 53.59 mg/100g. After cooking, a significant ($p< 0.05$) increase of both Mg and K was observed in all bean varieties. One serving of beans contains between 300 and 400 mg of potassium, which is similar to that provided by one serving of cow milk (Messina, 2014). However, cooking significantly reduced the P element in all common bean varieties. Cooking beans resulted in significant ($p< 0.05$) losses of Na in NUV130 and RWR2245 bean varieties only. The decrease in the level of different minerals in the different common bean varieties may be due to the leaching of the various minerals into the bean broth. This trend was reported by Saulawa *et al*. (2014b), and (Audu & Aremu, 2011), for the composition of minerals of thermally processed baobab seeds and red kidney beans.

Table III. Mineral content in raw and cooked beans

Variety	PT	Fe	Zn	Ca	Mg	K	P	Na
NUV30	Raw	98.25±0.89^{b}	47.92±0.59^{b}	782.60±1.98^{b}	1345.99±5.18^{b}	884.14±4.70^{b}	210.34±0.08^{a}	604.00±2.98^{b}
	Cooked	121.98±0.15^{a}	73.14±1.54^{a}	1110.14±13.05^{a}	1626.01±20.17^{a}	1226.37±12.58^{a}	114.19±2.22^{b}	614.96±1.11^{a}
RWV1129	Raw	61.41±2.22^{b}	39.53±1.59^{b}	604.55±2.32^{b}	1383.37±8.50^{b}	841.53±5.29^{b}	161.69±0.21^{a}	764.17±2.99^{b}
	Cooked	129.45±4.97^{a}	87.93±1.36^{a}	1263.37±5.86^{a}	1532.27±7.45^{a}	1203.87±8.36^{a}	116.55±1.38^{b}	883.96±1.21^{a}
RWR2154	Raw	61.34±0.87^{a}	30.75±1.37^{b}	727.92±2.99^{b}	1514.19±3.36^{b}	903.04±0.63^{b}	315.28±2.81^{a}	638.11±0.50^{b}
	Cooked	51.91±1.97^{b}	76.44±0.47^{a}	1024.41±3.17^{a}	1528.03±0.75^{a}	1063.52±1.24^{a}	222.05±1.35^{b}	735.93±0.10^{a}
NUV130	Raw	115.71±0.27^{a}	53.59±1.25^{b}	858.79±0.63^{a}	1217.54±2.79^{b}	899.17±3.45^{b}	159.75±0.58^{a}	592.48±1.62^{a}
	Cooked	44.40±2.52^{b}	62.35±0.35^{a}	616.55±0.33^{b}	1564.42±5.48^{a}	1107.26±4.26^{a}	103.35±0.90^{b}	570.78±0.14^{b}
NUV91	Raw	61.15±1.05^{b}	41.81±0.25^{b}	583.15±0.33^{b}	1586.02±2.19^{b}	987.30±0.77^{b}	154.76±1.76^{a}	686.29±0.70^{b}
	Cooked	108.05±0.76^{a}	92.28±0.47^{a}	1149.16±1.77^{a}	1750.30±0.08^{a}	1196.12±0.53^{a}	127.27±1.25^{b}	893.19±0.68^{a}
MAC44	Raw	61.95±0.68^{b}	20.34±1.06^{b}	1166.80±2.87^{a}	1500.62±0.86^{b}	890.60±0.43^{b}	178.65±0.56^{a}	707.31±0.38^{b}
	Cooked	66.31±1.02^{a}	53.27±0.35^{a}	1130.86±9.44^{b}	1736.04±11.09^{a}	1157.11±8.40^{a}	89.31±0.71^{b}	778.26±0.61^{a}
Kinure	Raw	71.62±0.34^{b}	35.28±0.95^{b}	846.00±7.31^{b}	1367.76±10.73^{b}	834.36±5.81^{b}	304.68±3.34^{a}	584.94±5.54^{b}
	Cooked	83.05±1.08^{a}	65.55±1.33^{a}	1246.31±3.13^{a}	2000.25±10.03^{a}	1690.28±7.23^{a}	229.08±1.88^{b}	744.84±0.94^{a}
Rusenyanzego	Raw	61.98±1.03^{b}	24.86±1.10^{b}	1019.53±7.68^{b}	1318.93±8.84^{b}	784.38±3.68^{b}	180.79±0.01^{a}	608.04±3.08^{b}
	Cooked	97.13±0.22^{a}	69.75±0.60^{a}	1369.96±1.29^{a}	1751.02±1.19^{a}	1011.59±0.25^{a}	136.02±0.78^{b}	748.75±0.16^{a}
RWR2245	Raw	59.41±2.04^{b}	41.55±1.39^{b}	637.29±3.74^{b}	1224.21±3.76^{b}	768.65±3.94^{b}	220.97±0.22^{a}	547.18±0.57^{a}
	Cooked	75.93±1.36^{a}	55.24±0.58^{a}	820.26±1.41^{a}	1530.42±5.29^{a}	958.67±1.98^{a}	134.84±0.73^{b}	536.58±2.94^{b}
MAC70	Raw	96.27±0.90^{a}	46.22±0.65^{a}	777.20±1.64^{b}	1188.30±1.94^{b}	722.09±1.97^{b}	280.45±1.27^{a}	754.63±1.98^{b}
	Cooked	69.13±1.73^{b}	40.48±0.13^{b}	1672.11±3.73^{a}	1960.29±2.62^{a}	1228.10±5.27^{a}	197.09±0.90^{b}	856.48±0.14^{a}
RWV1272	Raw	89.27±0.85^{a}	33.31±2.00^{b}	777.08±8.65^{a}	810.89±7.80^{b}	1266.06±13.54^{a}	210.61±0.33^{a}	800.03±9.73^{b}
	Cooked	62.60±0.15^{b}	74.03±0.27^{a}	669.49±3.93^{b}	2045.24±9.45^{a}	1304.01±4.83^{a}	120.62±0.35^{b}	900.26±0.24^{a}

Values are mean± standard deviations. Values along the column followed by different superscript letter notations are significantly different ($p < 0.05$).

2.9 The relationship between proximate composition and antinutrient

There was a significant positive relationship (r=0.38) between ash and protein content (Table IV) These values imply that a unit increase in ash or protein content would cause a unit increment of either factor by 38.00%. However, we contend that this relationship is weak. There was also a positive significant relationship (R=0.57) between crude fibre and fat content implying that an increment in fibre or protein would lead to a moderate increment in both variables by 57.00%. Additionally, a significant positive relationship was recorded between carbohydrates and condensed tannins (r=0.33). An increase in the carbohydrate or condensed tannins would cause a 33% increase in either variable. This relationship is however weak. Lastly, a significant positive relationship was recorded between condensed tannins and total phenolics (r=0.59), implying an increase in the concentration of either condensed tannins or total phenolics would cause a moderate increase in by 59.00%.

Table IV further shows there was a significant negative relationship between proteins and carbohydrates (r=-0.67). This observation implies that a unit increase in either protein or carbohydrate would cause a 0.67 decrease in either component. A significant negative relationship was also recorded between fibre and carbohydrates (r-0.69) and fibre and condensed tannins (r=-0.56. A unit increment in either fibre or carbohydrate. A unit increment in either fibre or carbohydrates would result in a 0.69 reduction in either component and a 0.56 decrease in fibre or condensed tannins. Furthermore, a significant negative relationship was reported between phytic acid and condensed tannins(r=-0.59), implying that increasing phytic acid or condensed tannins would result in a 0.59 decrease in either component.

Table IV. Correlation coefficients of interaction between proximate and anti-nutrients in biofortified beans on cooking

	Ash	**Protein**	**Fibre**	**Fat**	**CHO**	**PA**	**CT**	**TP**
Ash	1.000	**0.376*****	-0.087^{ns}	-0.055^{ns}	**-0.376*****	0.153^{ns}	0.217^{ns}	**0.466*****
Protein		1.000	0.032^{ns}	-0.021^{ns}	**-0.671*****	0.173^{ns}	0.018^{ns}	0.200^{ns}
Fibre			1.000	**0.566*****	**-0.687*****	0.197^{ns}	**-0.558*****	-0.225^{ns}
Fat				1.000	**-0.572*****	-0.043^{ns}	**-0.324*****	-0.219^{ns}
CHO					1.000	-0.222^{ns}	**0.328*****	-0.036^{ns}
PA						1.000	**-0.524*****	-0.140^{ns}
CT							1.000	**0.594*****
TP								1.000

Values are correlation coefficients significant ns-not significant, *-significant at p<0.05.**

CHO-Carbohydrates, PA-Phytic Acid, CT-Condensed Tannins, TP- Total Phenolics

Table V shows the effect of cooking on the nutritional characteristics and antinutrient components of the biofortified bean varieties and *Rusenyanzego* (traditional non-biofortified variety) with reference to the *Kinure* variety (control). There was no significant (p> 0.05) difference in the ash, protein, crude fibre, carbohydrates and crude fat content between the cooked and raw biofortified common bean varieties and *Rusenyanzego* with reference to *Kinure*. These findings indicate that the biofortified bean varieties and the two traditional common bean varieties did not differ in these parameters. However, phytic acid was significantly decreased (p<0.05) in only variety RWR2245 by 47.60% (p<0.05). Both total phenolics and condensed tannins were highly significant (p

<0.001) for all bean varieties with reference to the control variety (*Kinure*). Cooking reduced condensed tannins in all the bean varieties with the greatest reduction occurring in varieties MAC70 and RWR2245. These results imply that cooking reduced condensed tannins 3 times that it did in variety *Kinure*. Furthermore, cooking reduced total phenolic content in all the biofortified bean varieties with NUV130, RWR2154, and RWR1129 varieties showcasing a higher reduction, unlike the control variety, *Kinure.*

Table V. Logistic regression odds ratio estimates

Effect		Variety		Ash	Protein	Fibre	Fat	CHO	PA	CT	TP
Cooked	vs.	MAC44	PE	0.400^{ns}	0.789^{ns}	0.808^{ns}	1.250^{ns}	1.115^{ns}	0.856^{ns}	**1.110*****	**0.885*****
Raw			CL	(0.116-	(0.453-	(0.349-	(0.320-	(0.842-	(0.498-	**(1.008-**	**(0.836-**
				1.382)	1.372)	1.872)	4.882)	1.477)	1.470)	**1.223)**	**0.937)**
Cooked	vs.	MAC70	PE	0.733^{ns}	0.871^{ns}	0.985^{ns}	0.800^{ns}	1.007^{ns}	0.780^{ns}	**3.434*****	**0.834*****
Raw			CL	(0.240-	(0.520-	(0.431-	(0.247-	(0.753-	(0.452-	**(3.087-**	**(0.781-**
				2.239)	1.458)	2.252)	2.586)	1.347)	1.344)	**3.821)**	**0.891)**
Cooked	vs.	NUV130	PE	0.800^{ns}	0.966^{ns}	0.606^{ns}	0.562^{ns}	1.115^{ns}	0.699^{ns}	**2.875*****	**0.854*****
Raw			CL	(0.242-	(0.572-	(0.572-	(0.143-	(0.841-	(0.408-	**(2.572-**	**(0.812-**
				2.645)	1.632)	1.632)	2.206)	1.477)	1.196)	**3.214)**	**0.899)**
Cooked	vs.	NUV30	PE	0.889^{ns}	0.981^{ns}	0.808^{ns}	1.250^{ns}	1.012^{ns}	0.852^{ns}	**2.100*****	**1.722*****
Raw			CL	(0.274-	(0.593-	(0.349-	(0.320-	(0.759-	(0.500-	**(1.857-**	**(1.636-**
				2.886)	1.624)	1.872)	4.883)	1.350)	1.453)	**2.374)**	**1.813)**
Cooked	vs.	NUV91	PE	0.873^{ns}	1.020^{ns}	0.985^{ns}	0.250^{ns}	1.055^{ns}	0.793^{ns}	**0.593*****	**0.352*****
Raw			CL	(0.286-	(0.606-	(0.431-	(0.063-	(0.793-	(0.469-	**(0.527-**	**(0.336-**
				2.664)	1.716)	2.253)	1.000)	1.404)	1.340)	**0.669)**	**0.369)**
Cooked	vs.	RWR2154	PE	0.600^{ns}	0.910^{ns}	0.758^{ns}	0.667^{ns}	1.114^{ns}	0.780^{ns}	**2.187** ***	**1.943** ***
Raw			CL	(0.190-	(0.534-	(0.325-	(0.180-	(0.840-	(0.455-	**(1.957-**	**(1.845-**
				1.895)	1.552)	1.764)	2.463)	1.478)	1.337)	**2.444)**	**2.045)**
		RWR2245	PE	0.720^{ns}	0.690^{ns}	0.636^{ns}	0.667^{ns}	1.192^{ns}	**0.524***	**3.158*****	**0.903*****

Cooked	vs.		CL	(0.378-	(0.381-	(0.259-	(0.180-	(0.904-	(0.304-	**(2.858-**	**(0.856-**
Raw				0.517)	1.249)	1.567)	2.462)	1.571)	0.904)	**3.491)**	**0.953)**
Cooked	vs.	RWV1129	PE	0.800^{ns}	0.982^{ns}	0.909^{ns}	2.500^{ns}	1.025^{ns}	0.631^{ns}	**2.733*****	**1.844*****
Raw			CL	(0.242-	(0.592-	(0.361-	(0.515-	(0.771-	(0.370-	**(2.460-**	**(1.728-**
				2.645)	1.627)	2.289)	12.14)	1.362)	1.076)	**3.036)**	**1.967)**
Cooked	vs.	RWV1272	PE	0.400^{ns}	0.922^{ns}	0.631^{ns}	0.500^{ns}	1.187^{ns}	0.825^{ns}	**0.487*****	**0.486*****
Raw			CL	(0.143-	(0.558-	(0.267-	(0.141-	(0.888-	(0.480-	**(0.433-**	**(0.465-**
				1.118)	1.523)	1.492)	1.772)	1.587)	1.416)	**0.548)**	**0.507)**
Cooked	vs.	*Rusenyanzego*	PE	1.333^{ns}	1.081^{ns}	0.802^{ns}	1.250^{ns}	0.968^{ns}	1.150^{ns}	**0.486*****	**0.714*****
Raw			CL	(0.376-	(0.652-	(0.342-	(0.320-	(0.726-	(0.659-	**(0.437-**	**(0.682-**
				4.725)	1.792)	1.881)	4.883)	1.289)	2.006)	**0.542)**	**0.746)**

Variety *Kinure* is the reference category; PE= Point Estimate; CL= 95% Wald confidence Limits; *= significant at p<0.001; *=significant at p<0.05; ns= Not significant**

3.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, the different common bean varieties are good sources of proteins, crude fibre carbohydrates and minerals such as iron, zinc, calcium, magnesium and potassium. The biofortified common bean varieties also contain antinutrient such as condensed tannins, total phenolics and phytic acid which may tamper with absorption and digestibility of other nutrients. However, cooking, which is a thermal wet processing method greatly reduced the antinutritional levels in the biofortified common bean varieties and hence enhancing their nutrition quality. Based on this study, varieties MAC70 and RWR2245 had the highest reduction in phytic acid after cooking while varieties NUV130, RWR2154, and RWR1129 had the highest reduction in total phenolic content after cooking, unlike the control variety *Kinure*. Biofortified common bean varieties are therefore superior in terms of reduction of anti-nutrients when cooked compared to the traditional varieties. There is a need for sensitization to bean consumers concerning the nutrition benefits associated with the consumption of these new varieties. The significant reduction of the antinutrient in various varieties is evidence of improvement in the nutritional value of the biofortified common beans. Additionally, cooking imparted positively on the protein, ash, carbohydrates, crude fat and crude fibre content in the biofortified common bean varieties, an aspect that could impact positively the consumer acceptability of these varieties.

We recommend that bean breeders and other bean stakeholders conduct community nutrition outreaches to educate bean farmers and consumers on the nutritional benefits associated with consuming these varieties. Additionally, bean farmers and consumers should be educated on better preparation methods which involve soaking and cooking without the soaking water to reduce the antinutritional factors such as tannins which interfere with the absorption of minerals such as iron and zinc. Considering this study only utilised soaking as a pre-treatment to bean preparation, other methods such as fermentation can be explored and the impact of nutrient composition recorded to aid identify the best practices that can be promoted for optimal nutritional benefits.

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Carcass Characteristics and Sensory Quality of Broilers Fed on Extruded Sorghum [*Sorghum Bicolor* (L.) Moench] Meal and Exogenous Phytase-Based Diets

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Abstract

The interest in alternative energy sources in diets for sustainable poultry production is increasing. However, there is inadequate information on their effect on broiler production in terms of growth performance and meat quality. This study investigated the effect of extruded sorghum meal (ESM) and exogenous phytase enzyme on broiler carcass characteristics and descriptive sensory quality. A total of 108 day-old Cobb 500® chicks were weighed, grouped in six and randomly placed in deep litter cages. Each cage was randomly assigned one of the six dietary treatments with three replicates: T1 (0% ESM + 0% phytase), T2 (0% ESM + 0.035% phytase), T3 (50% ESM + 0% phytase), T4 (50% ESM + 0.035% phytase), T5 (100% ESM + 0% phytase), and T6 (100% ESM + 0.035% phytase). The grower and finisher diets were offered from days 1-21 and 22-42, respectively. After day 42, all broilers were weighed, and three randomly sampled from each treatment for carcass characteristics and descriptive sensory quality. The carcass weights and the weights of carcass parts were expressed as a percentage of live weight. A total of 10-12 panellists rated the sensory attributes of the meat on a quantitative descriptive analysis scale and just-about-right scale. Data was subjected to two-way analysis of variance in a completely randomized design using the general linear model procedure of the SAS Institute Inc. (version 9.4; 2015). Mean separation was done using Tukey's HSD test at 0.05 level of significance. Results showed that inclusion of ESM above 50% in the diets reduced carcass weights, abdominal fat, and gizzard weight. All sensory attributes were satisfactory. The inclusion of ESM up to 50% and exogenous phytase enzyme did not affect carcass characteristics or descriptive sensory quality. Thus, ESM may be included up to 50% with exogenous phytase enzyme in broiler diets without adversely affecting broiler carcass characteristics and descriptive sensory quality.

Keywords: descriptive, dressing percentage, gizzard, juiciness, tenderness,

Introduction

Despite a lot of attention being drawn to alternative energy sources to maize grain in poultry feeds, maize is still the most commonly used energy cereal in broiler feeds. Maize which is a staple food is demanded for biofuels production in developed countries, creating severe competition and thus increasing its global market price. This affects the sustainability of poultry production, and food and nutrition security, particularly in developing countries. Therefore, this has stimulated interest to evaluate alternative energy sources in poultry diets (Alshelmani et al., 2021).

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important food and feed cereal crop globally, after maize, wheat, rice, and barley (Awika & Rooney, 2004). In comparison with maize, sorghum is drought tolerant and does well under varying soil types. The nutrient composition of sorghum is similar to maize grain (Moritz et al., 2022). Therefore, sorghum is a potential alternative cereal energy source in poultry diets. However, some sorghum varieties contain a high level of tannins, kafirins and phytate which when fed without mitigation

adversely affect broiler performance (Moritz et al., 2022; Alshelmani et al., 2021; Awika & Rooney, 2004). The feed efficiency of broilers fed on sorghum is increased through feed processing methods such as extrusion cooking.

Extrusion cooking improves the nutritional value and feed efficiency of poultry feeds. Through this technology, the anti-nutritional factors in sorghum grain are inactivated. Moreover, there is more gelatinization, formation of soluble dietary fibre, and reduction of lipid oxidation (Singh et al., 2007). On the other hand, exogenous phytase optimizes growth, feed intake, feed conversion ratio, and the cost-benefit ratio in broilers fed on sorghum-based diets (Ahmed & Tanveer, 2021). The mechanism involves the destruction of the anti-nutritional properties of phytic acid/phytate, which frees bound phosphorous and other minerals.

Therefore, extruded sorghum meal with exogenous phytase enzyme is a potential alternative to maize grain in broiler diets. However, to determine its potential as an energy source in broiler diets, it is necessary to understand its effects on broiler carcass characteristics and sensory quality. Therefore, this study investigated the effect of extruded sorghum meal and exogenous phytase based-diets on broiler carcass characteristics and sensory quality.

MATERIALS AND METHODS

Ethical Consideration

This study was approved by the Egerton University Research Ethics Committee with approval number EUISERC/APP/224/2023 and the National Commission of Science and Technology of Kenya, with license number NACOSTI/P/23/25493.

Study Site

The study was undertaken at Egerton University in the Tatton Agriculture Park (feeding experiment) and the Department of Dairy and Food Science and Technology (carcass characteristics and sensory quality evaluation). The University is located in Njoro Sub-County, Nakuru County, at 0° 23' S, 35° 55' N. The altitude of the area is 2,238 m above sea level. The temperature of the area averages 21^{o}C and annual rainfall ranges between 900 to 1,020 mm (Egerton University Meteorological Station, 2019).

Experimental Design and Diets

A (3x2) factorial arrangement was used in a completely randomized design to determine the effect of extruded sorghum meal as an energy source at three inclusion levels (0, 50, and 100%) and exogenous phytase at two levels (with or without) on broiler carcass characteristics and sensory quality. There were six dietary treatments (Tables 1 and 2): T1 (0% ESM + 0% phytase), T2 (0 % ESM + 0.035 % phytase), T3 (50 % ESM + 0% phytase, T4 (50 % ESM + 0.035 % phytase), T5 (100 % ESM + 0 % phytase), and T6 (100 % ESM + 0.035 % phytase). Each treatment was replicated three times with six chicks per replicate. The model used was as follows;

$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk}$ *i=1,2,3; j=1,2;*

where;

Y_{ijk} is observation k in level i of extruded sorghum meal and level j of phytase;

μ is the overall mean;

A_i is the effect of level i of extruded sorghum meal;

B_j is the effect of level j of phytase;

$(AB)_{ij}$ is the effect of the interaction of level i of the extruded sorghum meal with level j of phytase;

ε_{ijk} is a random error with mean 0 and variance σ^2.

Table 1. Composition of experimental grower diets

Ingredient (% in the diet)	Dietary treatments T1	T2	T3	T4	T5	T6
Maize meal	56.4	56.4	28.2	28.2	0.0	0.0
ESM	0.0	0.0	28.2	28.2	56.4	56.4
Soybean meal	33.8	33.8	33.5	33.5	32.8	32.8
Fish meal (*Omena*)[1]	3.8	3.8	3.8	3.8	4.2	4.2
Vegetable oil	3.5	3.5	3.8	3.8	4.1	4.1
DCP	1.2	1.2	1.2	1.2	1.2	1.2
Limestone	0.5	0.5	0.5	0.5	0.5	0.5
Premix	0.5	0.5	0.5	0.5	0.5	0.5
Common salt	0.3	0.3	0.3	0.3	0.3	0.3
Natuzyme®	0	0.035	0	0.035	0	0.035
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
CP	23.3	23.3	23.3	23.3	23.3	23.3
ME (kcal/kg)	3155.5	3154.6	3151.8	3150.9	3148.8	3147.9
CF	2.5	2.5	2.5	2.5	2.5	2.5
Analysed composition (g/100g DM)						
CP	23.3±0.13	23.5±0.53	23.6±0.12	23.6±0.13	23.1±0.24	23.5±0.24
Ether extracts	11.9±0.29	12.1±0.61	9.92±0.29	8.80±0.20	9.39±0.06	9.53±0.12
CF	4.39±0.33	3.82±0.47	3.44±0.19	3.15±0.15	2.43±0.39	3.05±0.67

[1]Scientific name: Rastrineobola argentea, common name; silver cyprinid, and it's also called the Lake Victoria sardine or Mukene, [2]variety: 6213; ESM is extruded sorghum meal; DCP is Dicalcium phosphate; The premix per 2.5kg supplied: Vit A 10000000IU, Vit D3 2800000IU, Vit E 25000mg, Vit K_3 2800mg, Vit B_1 2000mg, Vit B_2 7000mg, niacin 40000mg, pantothenic acid 12000mg, Vit B_6 3500mg, folic acid 1000mg, Vit B_{12} 15mg, biotin 80mg, manganese 60000mg, zinc 60000mg, iron 30000mg

Table 2: Composition of experimental finisher diets

Ingredient (% in the diet)	Dietary treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Maize meal	65.0	65.0	32.5	32.5	0.0	0.0
ESM	0.0	0.0	32.5	32.5	65.0	65.0
Soybean meal	24.8	24.8	24.3	24.3	23.7	23.7
Fish meal (*Omena*)[1]	4.5	4.5	4.6	4.6	4.8	4.8
Vegetable oil	3.2	3.2	3.6	3.6	4.0	4.0
DCP	1.2	1.2	1.2	1.2	1.2	1.2
Limestone	0.5	0.5	0.5	0.5	0.5	0.5
Premix	0.5	0.5	0.5	0.5	0.5	0.5
Common salt	0.3	0.3	0.3	0.3	0.3	0.3
Natuzyme®	0	0.035	0	0.035	0	0.035
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
CP	20.1	20.1	20.1	20.1	20.1	20.1
ME (kcal/kg)	3204.2	3203.3	3203.6	3202.7	3203.1	3202.2
CF	2.4	2.4	2.5	2.5	2.5	2.5
Analysed composition (g/100g DM)						
CP	21.0±0.12	20.8±0.13	20.8±0.31	20.4±0.31	21.7±1.41	19.9±0.14
Ether extracts	10.7±0.19	10.4±0.19	9.69±0.12	9.72±0.18	10.1±0.21	10.0±0.35
CF	5.17±0.05	4.17±0.51	4.48±0.11	4.41±0.07	4.18±0.07	4.17±0.47

[1]Scientific name: Rastrineobola argentea, common name; silver cyprinid, and it's also called the Lake Victoria sardine or Mukene, [2]variety: 6213; ESM is extruded sorghum meal; DCP is Dicalcium phosphate; premix was similar as in the grower diet

Management of Birds

A total of one hundred and eight (108) healthy, mixed-sexes, day-old commercial broiler chicks (Cobb 500 breed) were purchased from the local commercial hatchery (Kenchic® Limited). The chicks were vaccinated against Gumboro and Newcastle diseases at the hatchery. On the first day, the chicks were administered Lemycin® (a water-soluble chick booster containing an antibiotic, glucose, vitamins, and amino acids) and liquid paraffin (to soften and lubricate droppings). The chicks were fed on a standard maize-soybean diet for the first 48 h while acclimatizing to the experimental conditions. On the third day post-hatching, chicks were weighed in groups of six and randomly allocated into eighteen cages. Chicks in each cage were randomly assigned to one of the six diets with 3 replicates. The grower diets were offered 1-21 d and the finisher diets 22-42 d. Water and feed were provided *ad libitum*.

Slaughter Method and Determination of Carcass Characteristics

All broilers were weighed at the end of the feeding experiment to obtain slaughter weight, and three broilers per treatment were sampled randomly for carcass characteristics and sensory quality evaluation. The broilers were starved for 8-10 h but with free access to water before slaughter. The slaughter involved stunning and severing the jugular vein and then allowing blood to drain for five minutes. The slaughtered birds were scalded in hot water (about 50^{o}C) for one minute to allow for the plucking of feathers and manual evisceration. The carcasses were dressed by removing the neck and the shank, chilled at 4^{o}C for 24 h and re-weighed to obtain the cold carcass weight.

The hot-dressed chicken (carcass) was weighed to calculate the dressing percentage by expressing the hot-dressed weight as the percentage weight of live chicken, as described by Maidala et al. (2020).

$$\text{Dressing percentage} = \frac{\text{hot dressed weight (g)}}{\text{slaughter weight (g)}} \times 100$$

The wings, breast, drumsticks, thigh and abdominal fat were removed, weighed, and expressed as a percentage of the weight of the live chicken. The skin between the thigh and the body was cut to expose and dislocate the hip joint (articulation *coxoe*). The tendons and ligaments around the joint were cut to remove the thighs. The thigh and the drumstick were separated at the stipple joint (articulation *genus*). A cut was made in the vertical side of the carcass at the shoulder joint (articulation *humeri*) to remove the wings. The breast was gently separated from the sternum using the tip of the knife.

Visceral organs (liver, heart and gizzard) were removed and measured in grams using a sensitive electric balance. The small intestine and large intestines were measured in centimetres (cm) using a tailor's flexible measuring tape. The weights of the various organs measured were expressed as a percentage of live weight.

Sensory Quality Evaluation

A total of 10-12 experienced semi-trained panelists aged 25-40 years, who were previously screened and trained, were selected to participate in the sensory evaluation for three days. The panelists learned how to identify and describe chicken sensory attributes. The descriptors and scales used were developed during the training. The sensory evaluation room was organized according to the recommendations of Lawless and Heymann (2010). The panelists evaluated various sensory attributes on both the quantitative descriptive analysis scale (Table 3) and the just about-right (JAR) scale.

Skinless breast muscles (pectoralis major) for the determination of carcass characteristics were thoroughly washed with clean water for sensory evaluation. The breast was chosen because it yields sufficient meat and it is one of the most commercially important chicken parts (Oloo, 2021). Each sample was boiled in a different pot for 45-60 min at 100^{o}C without adding any spice or salt. The samples were then deboned manually, cut into cubes of approximately 2 cm^3 and wrapped in aluminium foil to maintain a warm temperature. Each panelist was presented with 6 pieces every day for three days on white sensory-evaluation plates labelled with 3-digit blinding codes in a completely randomized design (six dietary treatments). The panelists were provided with warm water and biscuits for cleansing the mouth between each tasting.

Table 3. Descriptive of the 9-point hedonic scale used for quantitative descriptive sensory evaluation

	Attribute	Subjective ranking
1	Aroma intensity	(1 =Extremely bland to 9 = Extremely intense)
2	The initial impression of juiciness (moisture release)	(1 = Extremely dry to 9 = Extremely juicy)
3	First bite (initial hardness)	(1 = Extremely tough to 9 = Extremely tender)
4	Cohesiveness of mass	(1=Extremely loose to 9=Extremely compact)
5	Sustained impression of juiciness	(1 = Extremely dry to 9 = Extremely juicy)
6	Muscle fibre and overall tenderness (chewiness)	(1 = Extremely tough, to 9 = Extremely tender)
7	Amount of connective tissue (fibrousness)	(1= Extremely abundant to 9 = none)
8	Overall chicken flavor intensity	(1= Extremely bland to 9 = extremely intense)
9	White colour intensity	(1= None to 9 = Extremely intense)

The just About-Right (JAR) scale was used to evaluate the appropriateness of colour, texture, tenderness, juiciness, taste, flavor and overall acceptability (1 = too little, 5 = too much). The JAR scales were used because they indicate the reaction of consumers towards a specific attribute and can be used for diagnostics and explanation if the overall product appeal is lacking (Lawless & Heymann, 2010).

Statistical Analysis

Data were subjected to a two-way analysis of variance in a completely randomized design using the general linear model (GLM) procedure of the SAS Institute Inc. (version 9.4; 2015). The mean separation was done using Tukey's HSD test at a level of significance of 0.05. Pearson correlation coefficients were tabulated using the Proc Corr procedure to investigate any relationships between the sensory attributes.

RESULTS AND DISCUSSION

Table 4: Effects of dietary treatments on carcass characteristics of broilers

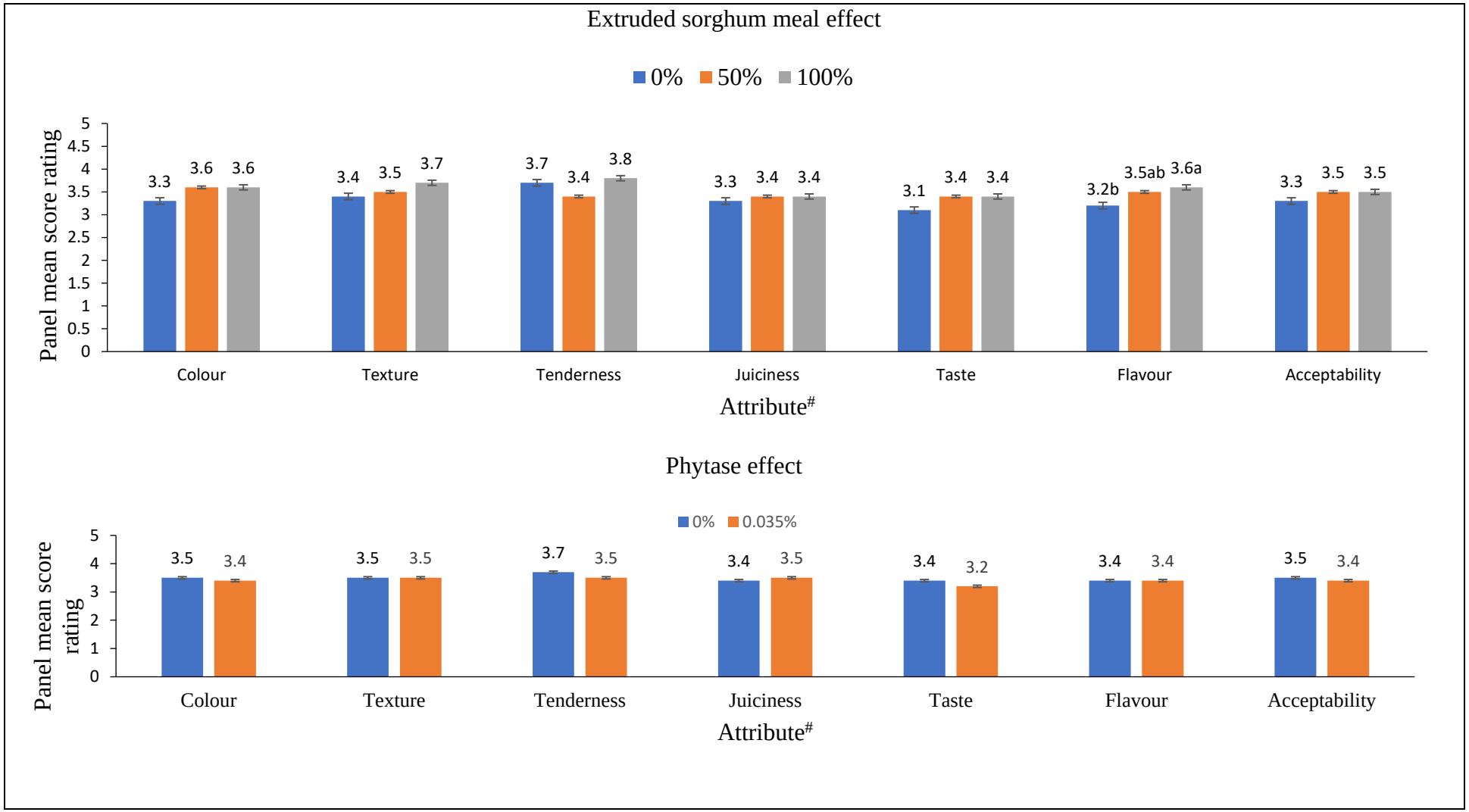
Parameter	ESM effect					phytase effect				ESM× phytase
	0%	50%	100%	SEM	*p*-value	0%	0.035%	SEM	*p*-value	*p*-value
Slaughter weight (g)	1078.2[a]	962.0[a]	395.2[b]	70.3	*	776.6[a]	847.0[a]	57.4	ns	ns
Hot carcass weight (g)	889.7[a]	790.3[a]	320.5[b]	59.1	*	633.7[a]	700.0[a]	48.2	ns	ns
Cold carcass weight (g)	884.2[a]	746.2[a]	318.8[b]	62.2	*	630.1[a]	669.3[a]	50.8	ns	ns
Dressing weight (%)	82.5[a]	81.9[a]	81.0[a]	0.7	ns	81.1[a]	82.5[a]	0.5	ns	ns
Wing weight (%)	9.4[a]	9.9[a]	9.2[a]	0.4	ns	9.5[a]	9.5[a]	0.3	ns	ns
Breast weight (%)	22.4[a]	20.4[a]	19.7[a]	0.8	ns	21.6[a]	20.1[a]	0.6	ns	ns
Drumstick weight (%)	11.3[a]	11.5[a]	9.6[a]	0.6	ns	10.8[a]	10.8[a]	0.5	ns	ns
Thigh weight (%)	13.4[a]	12.2[a]	15.2[a]	2.8	ns	15.3[a]	11.9[a]	2.3	ns	ns
Abdominal fat weight (%)	2.3[a]	1.7[ab]	1.2[b]	0.2	*	1.6[a]	1.8[a]	0.1	ns	*
Liver weight (%)	2.1[a]	2.2[a]	2.6[a]	0.1	ns	2.3[a]	2.3[a]	0.1	ns	ns
Gizzard weight (%)	2.6[b]	3.0[ab]	3.7[a]	0.2	*	3.2[a]	3.0[a]	0.2	ns	ns
Heart weight (%)	0.8[ab]	0.7[b]	0.9[a]	0.1	ns	0.9[a]	0.8[a]	0.0	ns	ns
Small intestine length (cm)	157.0[a]	172.7[a]	146.2[a]	7.3	ns	151.8[a]	165.4[a]	5.9	ns	ns
Large intestine (cm)	27.8[a]	30.0[a]	25.2[a]	1.3	ns	28.7[a]	26.7[a]	1.1	ns	ns

[a, b] means in the same row with different superscripts are significantly different ($p < 0.05$); * is significant at $p < 0.05$; ns is not significant at $p < 0.05$; ESM is extruded sorghum meal; SEM is the standard error of the mean.

Table 5: Descriptive sensory attributes scores of broiler breast meat as influenced by dietary treatments on a hedonic scale

Attribute[#]	**ESM effect**					**phytase effect**				**ESM× phytase**
	0%	**50%**	**100%**	**SEM**	***p*-value**	**0%**	**0.035%**	**SEM**	***p*-value**	***p*-value**
Aroma intensity	5.4[b]	5.9[ab]	6.3[a]	0.181	*	6.1[a]	5.6[b]	0.147	*	ns
The initial impression of juiciness (moisture release)	5.9[a]	6.2[a]	6.4[a]	0.178	ns	6.3[a]	6.0[a]	0.145	ns	ns
First bite (initial hardness)	4.5[a]	5.1[a]	5.2[a]	0.229	ns	5.1[a]	4.8[a]	0.187	ns	ns
Cohesiveness of mass	5.7[a]	6.0[a]	5.9[a]	0.209	ns	5.9[a]	5.8[a]	0.171	ns	ns
Sustained impression of juiciness	5.5[b]	6.1[ab]	6.6[a]	0.209	*	6.0[a]	6.1[a]	0.170	ns	ns
Muscle fibre and overall tenderness (chewiness)	5.4[b]	6.0[b]	7.1[a]	0.212	*	6.2[a]	6.1[a]	0.173	ns	ns
Amount of connective tissue (fibrousness)	5.7[a]	5.9[a]	6.2[a]	0.208	ns	6.1[a]	5.8[a]	0.170	ns	ns
White colour intensity	5.9[a]	5.5[ab]	4.9[b]	0.213	*	5.7[a]	5.2[b]	0.174	*	ns
Overall chicken flavor intensity	5.5[b]	5.9[ab]	6.3[a]	0.190	*	6.0[a]	5.8[a]	0.156	ns	ns

[a, b] means in the same row with different superscripts are significantly different ($p< 0.05$); [#]Sensory attributes evaluated on a scale from 1 to 9, where 1 is lowest intensity and 9 is highest intensity; * is significant at $p< 0.05$; ns is not significant at $p< 0.05$; ESM is extruded sorghum meal; SEM is the standard error of the mean.



#the scale ranged from 1 to 5, (1 = too little, 5 = too much); a, b means in the same attribute with different letters are significantly different ($p < 0.05$)

Figure 8. JAR scores for broiler sensory attributes as influenced by the dietary treatments

Table 6. The correlation coefficients of the sensory attributes on the hedonic scale rating

	AI	**IJ**	**FB**	**MC**	**SI**	**CH**	**F**	**C**	**OCF**
Aroma intensity (AI)	1.0000	0.28357*	0.12636ns	0.30576*	0.39394*	0.2646*	0.28219*	0.19711*	0.49762*
Initial juiciness (IJ)		1.0000	-0.0631ns	0.35556*	0.57661*	0.13171ns	0.20279*	-0.0103ns	0.16553*
First bite (FB)			1.0000	0.21013*	0.01432ns	0.28819*	0.13022ns	0.04138ns	0.12615ns
Mass cohesiveness (MC)				1.0000	0.36529*	0.03797ns	0.53942*	0.1329ns	0.22175*
Sustained impression (SI)					1.0000	0.32057*	0.35568*	0.11969ns	0.48197*
Chewiness (CH)						1.0000	0.00216ns	0.13382ns	0.23083*
Fibrousness (F)							1.0000	0.20849*	0.42861*
Colour (C)								1.0000	0.20375*
Overall chicken flavor (OCF)									1.0000

*is significant at $p< 0.05$; ns is not significant at $p< 0.05$

Table 7. The correlation coefficients of the sensory attributes on the JAR scale

	Colour	**Texture**	**Tenderness**	**Juiciness**	**Taste**	**Flavor**	**Acceptability**
Colour	1.0000	0.28233*	0.17928*	0.25634*	0.44183*	0.42610*	0.50170*
Texture		1.0000	0.28081*	0.13863ns	0.25416*	0.32244*	0.28593*
Tenderness			1.0000	0.14442ns	0.16113*	0.26086*	0.20528*
Juiciness				1.0000	0.40055*	0.40203*	0.42987*
Taste					1.0000	0.54344*	0.69405*
Flavor						1.0000	0.59670*
Acceptability							1.0000

*is significant at $p< 0.05$; ns is not significant at $p< 0.05$

Carcass Characteristics

As shown in Table 4, the ESM significantly affected broiler carcass characteristics while exogenous phytase enzyme did not affect the broiler carcass characteristics.
The inclusion of ESM in the diet influenced the broiler slaughter weights, hot carcass weights and cold carcass weights. Inclusion at 50% did not affect slaughter weight, hot dressed weight and cold dressed weight compared to control but they were decreased at 100% inclusion. The reduction in the carcass traits at a 100% inclusion level was attributed to higher levels of dietary anti-nutritional factors (tannins, kafirins and phytate) which adversely affected feed intake, weight gain, and feed efficiency during the feeding period (Zarei et al., 2022). This agrees with the work of Moses et al. (2022), where there was a reduction in hot carcass weights, and cold carcass weight in broilers fed on red sorghum-based diets compared to those fed on white sorghum-based diets. However, in the current study, the dressing percentage was not affected as was the case in Moses et al. (2022) study.

The abdominal fat decreased by 48% when ESM completely replaced maize in the diet. This was attributed to low crude fat in ESM compared to maize which reduced abdominal fat accumulation in broilers. This was consistent with the findings of Adamu et al. (2012), who observed a 77 % reduction in abdominal fat in broilers fed on yellow sorghum-based diets. Similarly, Cherian et al. (2002) observed a reduction in abdominal fat in broilers fed on sorghum-based diets. There was an ESM-phytase interaction effect for the abdominal fat of the broilers.

The broilers fed on ESM-based diets had relatively heavier gizzards than those fed maize-based diets. The development of the gizzard is stimulated by bigger feed particle size (Yan et al 2022; Nir et al., 1994). During milling the particle size reduction depends on several factors including the type of grain and hardness of the endosperm. Although milling of the experimental diets was done using the same hammer mill under similar conditions, the rate of particle size reduction in maize and ESM may have varied (Amerah et al., 2007). ESM particles were likely coarser than maize. This observation suggests that during milling, different sieve sizes may be necessary depending on grain type to achieve the desired particle size distribution. The coarseness of feed particles has been found to stimulate an increase in the relative weight of the gizzard in broilers (Idan et al., 2023; Moses et al., 2022; Yan et al., 2022). However, the other parameters were not affected by dietary treatments ($p > 0.05$).

Sensory quality

Broiler sensory attributes scores in hedonic and just-about-right scales were summarized in Table 5 and Figure 1, respectively. The correlation coefficients were presented in Tables 6 and 7. The inclusion of ESM in the diets enhanced aroma intensity, the sustained impression of juiciness; chewiness, and overall chicken flavor but reduced the white colour intensity of the meat. The incorporation of exogenous phytase increased aroma intensity and reduced white colour intensity. There was an increase in aroma and overall chicken flavor intensity in the meat of broilers fed on ESM-based diets. Aroma and flavor in meat depend on species, age, fatness, type of tissue, locality, gender, diet and method of cooking (Oloo, 2021; Webb et al., 2005). The increase in aroma/flavor in the current study may be attributed to the antioxidant properties of sorghum polyphenols (Awika, 2003). During storage of meat, lipids may be oxidized causing off-flavors (cardboard, painty, fishy, and warmed-over flavor) which are not liked by consumers (Lawless & Heymann, 2010). The antioxidants in ESM may have prevented lipid oxidation during storage thus retaining the natural aroma and overall chicken flavor. Similar findings are documented by Waters et al. (2018).

The breast meat of broilers fed on ESM was chewier than those fed maize-based diets. The toughness of meat is influenced by three types of muscle protein; connective tissue protein, myofibrils, and sarcoplasmic proteins. The main structural protein in connective tissue, collagen, affects the toughness of meat (Asghar et al., 1985). The amount of collagen in the muscle increases as body fat decreases (Purwanti et al., 2019), which may have increased chewiness in the meat of broilers fed on ESM-based diets. This was consistent with the work of Lyon et al. (2004) where broilers fed on sorghum-based diets scored higher for chewiness than those fed on maize-based diets.

The white colour intensity was reduced in the breast meat of broilers fed on ESM-based diets due to the presence of a red pigment, 3-deoxyanthocyanidins, in the ESM (Xiong et al., 2022). This confirms the findings of Cabral et al. (2018) where the meat colour of chicken fed on sorghum bran was darker than those fed the control.

The effect of exogenous phytase in reducing the aroma and white colour intensity was not clear in the current study. Although the enzyme breaks down phytate to liberate bound phosphorus and other minerals, it was not clear if this hydrolysis formed sensory active molecules. Similar results where the enzyme influenced the sensory quality of meat were found by Yasar et al. (2018).
In the hedonic scale, the most notable correlations were between, initial juiciness and sustained impression of juiciness (r= 0.58). The two, are descriptors of juiciness. The mass cohesiveness and fibrousness which describe texture were also correlated (r= 0.54). In the JAR scale, the overall acceptability was more correlated to taste (r= 0.69), flavor (r= 0.60) and colour (r= 0.50). Thus, taste, flavor, and colour were the most important attributes relied upon by the panelists to decide on the acceptability of the broiler meat. Flavor and taste were closely correlated (0.54). Colour was correlated with all sensory attributes analyzed thus it influenced the way the panelists perceived the other attributes (Lawless & Heymann, 2010).

CONCLUSION AND RECOMMENDATION

The inclusion of ESM as an energy source at 50% did not affect broiler carcass characteristics and sensory quality. Therefore, ESM may conveniently replace 50% of maize in broiler diets.

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CONFLICT OF INTEREST

The authors declare no conflict of interest for this article.

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Single Nucleotide Polymorphisms in Selected Candidate Genes and their Association with Body Weight in *Gallus Domesticus* Ecotypes

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Abstract

Indigenous chickens (IC) are known for their variability in body weight. Genetic studies have shown that body weight is polygenic. A total of 234 IC belonging to six ecotypes were used to evaluate the effect of ecotype on bodyweight (BW) and to determine the association between BW and single nucleotide polymorphism (SNPs) involved in growth. The genes were Neuropeptide Y (*NPY),* Dopamine receptor D2 (*DRD2),* **Bone morphogenetic protein receptor 1B** *(BMPR1B)* and M**elanocortin 1 receptor (***Mel1C)* from a diverse population of IC ecotypes. The association between the generated SNP profiles and BW was investigated. The results showed that average BW ranged from 0.6 to 2.60 kg. There were significance differences in BW between sexes ($p<0.01$) and ecotypes ($p<0.05$). The average BW was 1.38±0.32kg and 1.20±0.29kg for male and female chickens, respectively. The average BW was highest in SNNPR (1.39±0.07 kg) and Tigray (1.36±0.05kg) ecotypes. Other ecotypes had average BW of 1.26±0.03kg (Amhara), 1.13±0.01kg (Afar), 1.18±0.06kg (Gumuz) and 1.06±0.04kg (Oromia). Nine SNPs (*NPY*-3; SNP rs794226974, p-value=1.924; rs15938915, p-value=1.972 and rs738097857, p-value =1.685); *Mel1C*-3 (SNP rs734475748, p-value=3.219, SNP rs317836677, p-value=2.92 and SNP rs315819466, p-value=2.92), *DRD2*-2 (SNP rs313898728, p-value=2.28 and SNP rs732873238, p-value=2.166) and *BMPR1B*-1 (rs13524270) were associated with BW. The results indicate that SNPs on *BMPR1B, NPY, DRD2* and *Mel1C* genes are associated with the BW trait and are potential markers for use in molecular marker-assisted selection programs.

Key Words: QTLs, Candidate Genes, Genomic Selection, GWAS

1.0 INTRODUCTION

Indigenous chickens (*Gallus Gallus Domesticus*) are the most popular poultry species globally due to their economic, social and cultural significance (Gheyas *et al.*, 2022). The primary reason for domesticating indigenous chickens (ICs) in Africa was their sociocultural significance, with their role as a food source emerging later to meet the needs of a rapidly growing population (Clutton-Brock, 1992). Indigenous chicken make significant contributions to household food and income security (Muchadeyi *et al*., 2007). In Ethiopia, ICs accounts for over 90% of the national chicken meat and egg production (Gheyas *et al.*, 2022).

Indigenous chickens are traditionally kept under free-range system characterized by small-size unimproved flocks, which are left to scavenge with little or no supplemental feeding, housing and veterinary care (Dana *et al.,* 2010). Studies have shown that ICs are relatively poor producers of meat due to their slow growth rates and low mature weights (Ngeno *et al.*, 2013). As a result, they are gradually losing their importance in the rural villages (Mathur *et al*., 1989). This is a important constraint, that could be overcome through genetic improvement (Yuan *et al.,* 2018). Indiscriminate introduction of exotic genetic material through crossbreeding programmes has been considered a potential solution to low productivity. However, this approach has led to the dilution and loss of valuable genetic variability of IC genotypes (FAO, 2007; Besbes, 2009).

High demand of IC meat, occasioned by the ever-increasing human population and coupled with its highly preferred taste and suitability for special dishes, has resulted in higher market prices (Islam and Nishibori, 2009; Al-Jaryan *et al.,* 2021**).** The market price of chickens is primarily determined by body weight (BW). Consequently, BW is the most important selection criterion used by farmers (Gebremariam *et al*., 2017; Dana *et al.,* 2010). Improvement of BW will have a greater positive impact on the livelihoods of rural households (Magothe *et al.,* 2010).

Body weight of chickens can be classified into three categories: large body weight (LBW), with adult males weighing more than 3kg and adult females weighing between 2.0 and 3.0kg; small body weight (SBW), with adult males weighing less than 2kg and adult females weighing between 0.9 and 1.5kg; and medium body weight (MBW), between LBW and SBW (Wang *et al.,* 2023). However, ICs are characterized by their small body size (Mebratu, 1995). A study on the growth performance of seven IC populations in Ethiopia indicated that average BW at age of 22 months ranged from 1 to 1.5 kg and 0.642 to 0.874 kg for males and females, respectively. This is lower than the average weights of 1.74 and 1.26 kg for the respective sexes of the Rhode Island Red breed kept under the same conditions (Halima *et al*., 2009).

Increasing the IC's meat production efficiency requires genetic improvement, which depends on existing genetic variation and effective selection methods for exploiting it (Muchadeyi *et al.,* 2007). Moderate heritability estimates for BW have been reported in IC, indicating that additive genetic variance for this trait exists and is likely to result in genetic gain through selective breeding (Ohagenyi *et al.,* 2023; Kanlisi *et al.,* 2022; Taffa *et al.,* 2022**;** Khobondo, 2021; Osei-Amponsah *et al.,* 2013; Besbes, 2009).

Application of molecular markers is a potential tool to improve BW (Andini *et al.,* 2019). Body weight is highly polygenic, and several regions and chromosomes (GGA9 and GGA27) have been identified to influence BW in four Chinese indigenous chicken breeds (Chahua, Silkie, Langshan, and Beard), (Yuan *et al.,* 2018; Kanlisi *et al.* 2022). Several genes, such as *GH* (Kazemi *et al.*2018; Mehdi and Reza, 2012), *ACTA*-1 (Andini *et al.,* 2019), Insulin-like growth factor binding protein-2 (*IGFBP*-2) (Zhao *et al.,* 2015), *GNPDA2* (glucosamine-6-phosphate deaminase 2 gene (Ouyang *et al.* 2016), *ODC* and *PRDM16* (Cahyadi *et al.* 2013) among others, have been reported to influence BW.

Candidate genes are unique to each domestic chicken population, as their functions relate to adaptation, production, reproduction, and immunity (Lawal *et al.,* 2018). Several studies have associated *BMPR1B*, *DRD2*, *NPY,* and *Mel1C* genes with egg production traits. However, few have attempted to study the association of these genes with BW (Promket *et al.,* 2023). No study

has been done to determine the association of SNPs in *BMPR1B*, *DRD2*, *NPY* and *Mel1C* genes with BW in IC. Therefore, we hypothesized that SNPs within *BMPR1B*, *DRD2*, *NPY,* and *Mel1C* genes are associated with BW in IC ecotypes. The aim of this study was to identify SNPs within the *BMPR1B*, *DRD2*, *NPY,* and *Mel1C* genes that are associated with BW. Identifying SNPs contributing to variation in BW will improve future breeding programs utilizing Market Assisted Selection (MAS).

2.0 MATERIALS AND METHODS

2.1 Study Animals

The birds used in this study were sampled from 24 villages or 'kebeles' across six regional states of Ethiopia – Afar, Amhara, Gumuz, Oromia, SNNPR (Southern Nations, Nationalities and Peoples' Region), and Tigray as described by Gheyas*et al.* (2022). Chicken sampling considered various agro-climatic, ecological conditions, and geography. Each regional state was considered as a separate ecotype. To capture heterogeneity within populations, 8 to 10 chickens were sampled randomly from each village. A total of 234 IC birds were selected randomly from 6 ecotypes; Afar (16), Amhara (105), Gumuz (13), SNNPR (18), Tigray (43), and Oromia (17). The samples consisted of 146 female and 88 male birds and varied in their ages (4–30 months; average 10.3 months) and body weights (0.6–2.6 kg, average 1.27 kg).

2.2 Phenotyping

The weight of the birds (in kilograms) was recorded once by using digital scale with sensitivity of 1g.

2.3 Genotyping

2.3.1 Blood Sampling, Genomic DNA Extraction and Quality Control

Blood (50–250 µl) was drawn from the wing vein of each bird with syringes and cryotubes filled with 1.5 ml absolute ethanol (100%), following the guidelines available at https://www.sheffield.ac.uk/nbaf-s/protocols_list. DNA was extracted at the BecA-ILRI Hub facility, Nairobi, Kenya (http://hub.africabiosciences.org/), using the Qiagen DNeasy blood and tissue kit protocol (https://www.qiagen.com/ca/resources/download.aspx?id=63e22fd7-6eed-4bcb-8097-7ec77bcd4de6&lang=en). DNA concentration was evaluated by spectrophotometry using a Thermo Scientific Nano-Drop Spectrophotometer 2000c, and the quality and quantity of DNA were confirmed by agarose gel electrophoresis. The genomic DNA (gDNA) from each sample was normalized to a final volume of 100 µl and a final concentration of 50 ng/µl, was sent to Edinburgh Genomics, UK for whole genome sequencing (WGS). At Edinburgh Genomics, gDNA samples were re-evaluated for quantity and quality using an AATI Fragment Analyzer and the DNF-487 Standard Sensitivity Genomic DNA Analysis Kit https://www.agilent.com/cs/library/usermanuals/public/quick-guide-dnf-487-genomic-dna-kit-SD-AT000137.pdf. The AATI ProSize 2.0 software (https://dna.biotech.iastate.edu/fragmentanalyzer.html) was used to check the quantity and quality (integrity) score for each gDNA sample. Samples with a score above 7 passed quality control. The gDNA samples were pre-normalized to fall within the acceptable range for library preparation.

2.3.2 Library Preparation and Quality Control

Next generation sequencing libraries were prepared using Illumina SeqLab specific TruSeq Nano High Throughput Library preparation kits together with the Hamilton MicroLab STAR and Clarity

LIMS X Edition. The normalized gDNA samples were clipped to a 450 bp mean insert size using a Covaris LE220 focused-ultrasonicator. The inserts were ligated with blunt ended; A-tailed, size selected TruSeq adapters, and enriched using eight cycles of PCR amplification. The libraries were evaluated for mean peak size and quantity using the Caliper GX Touch with a HT DNA 1k/12 K/HI SENS LabChip and HT DNA HI SENS Reagent Kit. The libraries were normalized to 5 nM using the GX data, and the actual concentration was established using a Roche LightCycler 480 and a Kapa Illumina Library Quantification kit and Standards (https://rochesequencingstore.com/wp-content/uploads/2017/10/KAPA-Lib-Quant-ILMN_9.17-IfU_1.pdf).

2.3.3 Sequence Alignment and SNP Calling

The libraries were denatured and pooled in groups of eight for clustering and sequencing using a Hamilton MicroLab STAR with Genologics Clarity LIMS X Edition. Libraries were clustered onto HiSeqX Flow cells v2.5 on cBot2s, and the clustered flow cells were transferred to a HiSeqX for sequencing using a HiSeqX Ten Reagent kit v2.5. Sequencing was performed in paired-end mode with read length of 150 bp.

Demultiplexing was performed using bcl2fastq (v2.17.1.14), allowing a single mismatch when assigning reads to barcodes. Adapters
(Read1: AGATCGGAAGAGCACACGTCTGAACTCCAGTCA, Read2: AGATCGGAAGA GCGTCGTGTAGGGAAAGAGTGT) were trimmed during the demultiplexing process. Sequencing data quality was checked using the FASTQC package (v0.11.5). FASTQC reports for all samples were aggregated in a single report by the MultiQC package for easy review of sequence quality. No quality-based trimming was performed on the sequence reads prior to mapping and sequencing data from all samples were processed.

Sequence reads were mapped against the latest version of chicken reference genome (GCA_000002315.5_GRCg6a) using the BWA-mem (v0.7.15) algorithm. The resulting SAM/BAM files from the mapping step underwent a series of further processing steps, including coordinate sorting (using the SortSam function in Picard v2.9.2), duplicate reads marking (using Mark Duplicates function in Picard) and Base Quality Score Recalibration (BQSR) using GTAK v3.8-0. The final recalibrated BAM files were then used for variant calling.

Variant calling was performed following the GATK v3.8-0 best practice protocol for "Germline short variant discovery" using the Haplotype Caller function on individual samples followed by joint genotyping (using Genotype GVCFs function) of the samples. Variant filtration was performed by applying the Variant Quality Score Recalibration (VQSR) approach in GATK (v 3.8-0) using about one million validated SNPs as a training and true set, and over 20 M known chicken SNPs from the Ensemble database as known variants.

SNPs were extracted from the chicken genome using Vcftools v0.1.16 (Danecek *et al.*, 2011). The position of each gene based on the latest version of chicken reference genome (GCA_000002315.6_GRCg6a) as shown below.

Table 1: Position of Selected Genes on the chicken reference genome (GCA_000002315.6_GRCg6a)

Gene	Assembly	Chr	Location
DRD2	GCF_000002315.6(GRCg6a)	24	Chr24: 5,740,646 - 5,763,539
NPY	GCF_000002315.6(GRCg6a)	2	Chr2: 31,464,139 - 31,472,048
BMPR-1B	GCF_000002315.6(GRCg6a)	4	Chr4: 58,350,823 - 58,589,309
Mel1C	GCF_000002315.6(GRCg6a)	4	Chr4: 17,605,471 – 17,631,574

During the VQSR step the following annotations or context statistics were considered: read depth (DP), variant quality by depth (QD), root mean square of mapping quality (MQ), mapping quality rank sum test statistic (MQRankSum), read position rank sum test statistic (ReadPosRankSum), and strand bias statistics (FS and SOR). A tranche sensitivity threshold of 99% was applied for filtering variants.

As the final quality control of the called variants, any SNPs with a missing genotype rate of more than 20% across the samples were filtered out using VCF tools (option – max-missing 0.8). Resultant SNPs were further subjected to the following filtering criteria in Plink v1.9 software (Purcell *et al.*, 2007); minimum SNP quality of 20, 5% missing SNP genotypes, Hardy–Weinberg equilibrium (p <10−6), call rate >95%, heterozygosity >0.4, and minor allele frequency >0.05. For each chromosome, Tassel 5.2.60 estimated pairwise linkage disequilibrium (Bradbury *et al.*, 2007). Autosomal SNPs were pruned using indep-pairwise parameters described by Wang *et al.* (2009), resulting in 426,656 independent SNPs.

2.4 Statistical Analysis

The effect of ecotypes and sex on BW was performed using SAS 9.4 (SAS, 2016). Significant differences between the means of the ecotypes and sexes were assessed using Least Squares Means (LSMeans). Analysis of variance (ANOVA) was employed in the analysis using the General Linear Model Procedure of SAS 9.4 (SAS, 2016). The BW data was analyzed for descriptive statistics to obtain mean, minimum, maximum and standard errors for BW measurements. Due to missing values, only 193 observations were used in this analysis. The model was fitted for the effect of ecotypes, sex, and the interaction between ecotype and sex, with age as covariate:

$$\boldsymbol{Y_{ijk}}=\mu+\beta_{\boldsymbol{i}}+\alpha_j+(\beta x\alpha)_{ij}+k_{\S}+\boldsymbol{e_{ijk}}$$

where;
Y_{ijk}= the observed body weight of k_{th} individual chicken
μ = overall mean
$\beta_{\boldsymbol{i}}$ = fixed effect of i_{th} ecotype
α_j = fixed effect of j_{th} sex
$(\beta x\alpha)_{ij}$= fixed combined effect of i_{th} ecotype and j_{th} sex
$k_{\S}$ =age of the birds fitted as a covariate
e_{ijk}= random error

Multidimensional scaling (MDS) based on the centred identical-by-state (IBS) approach was used to test the population structure. Pairwise IBS distances were computed using independent SNPs. Multidimensional scaling (MDS) components were got using the MDS-plot option based on the IBS matrix. Due to the internal population structure, the first MDS component was included as a covariate in the statistical model for assessing SNP effects on body weight to account for sample stratification. Tassel 5.2.60 was used to construct a relative kinship matrix (K) using independent SNP markers (Bradbury *et al.,* 2007).

The analysis for genome-wide association study (GWAS) was performed using Tassel 5.2.60 (Bradbury *et al.,* 2007). SNPs significantly associated with BW were identified using the following mixed linear model (MLM) as implemented in Tassel (Zhang *et al.,* 2010).

$$\mathbf{Y} = \mathbf{X} + \mathbf{Zu} + \mathbf{e}$$

where;

Y is the vector of body weight;

β, vectors containing fixed effects (sex, ecotypes, and SNPs) and covariates (population structure);

u, a vector of random effect of the relative kinship matrix constructed by matrix simple matching coefficients based on the independent SNPs;

e, a vector of random residuals;

X and *Z* are design matrices.

Associations between markers and mean phenotypic values were identified using the population membership estimates as covariates to control for population structure. Associations were considered statistically significant at $p < 0.05$. Based on the estimated number of independent SNP markers, the threshold value of *p* of the 5% Bonferroni genome-wide significance was computed. The threshold value of *p* of the 5% Bonferroni genome-wide significance was used. An extensive mapping of all values of *p* for BW SNP markers was observed using the Manhattan plot in Tassel 5.2.60 (Bradbury *et al.,* 2007).

3.0 Results

The results of descriptive statistics BW are reported in Table 2 below. The BW of IC studied varied across the ecotypes. Body weight ranged from SNNPR (1.00-2.00 kgs), Tigray (0.80-2.60 kgs), Amhara (0.70-2.00 kgs), Afar (0.60-1.70 kgs), Gumuz (0.60-1.90 kgs and Oromia (1.0-1.50 kgs). SNNPR and Tigray ecotypes had the highest mean BW (1.39±0.07kgs) and 1.36±0.05, respectively Oromia ecotype had the lowest BW (1.06±0.04kgs). Other ecotypes Amhara, Afar and Gumuz had (1.27±0.03kgs), (1.13±0.1) and (1.18±0.06), respectively.

The BW in the present study compares well with one reported by Dana *et al.* (2010b) where the weight ranged from 1.4 (Konso) to 1.7kg (Horro), for males, and 1.0 (Konso) to 1.5kg (Sheka) for females. Mean BW of males and females varied significantly among the ecotypes.

Table 2: Descriptive Statistics of Body Weight of Ethiopian IC Ecotypes

Ecotype	N	Mean (SE)	Minimum	Maximum	p-value
SNNPR	18	1.39±0.07	1.00	2.00	0.1378
Tigray	39	1.36±0.05	0.80	2.60	0.6698
Amhara	102	1.27±0.03	0.70	2.00	0.9713
Afar	12	1.13±0.1	0.60	1.70	0.1727
Gumuz	6	1.18±0.06	0.60	1.90	0.6341
Oromia	17	1.06±0.04	1.00	1.50	0.185

The average BW for male was (1.38±0.32kgs) and female (1.20±0.29kgs). This is similar to with one reported by Dana (2010b) in Mandura, Horro, Sheka Farta and Konso populations. The mean BW found in this study was lower than 1.676±0.24kg and 1.313±0.13kg for males and females, respectively, in Rwanda IC **(**Mbakaya *et al.*, 2022**)** and lower than1.8kg and 1.7kg for mature male and 1.37kg and 1.35kg for mature female in Ethiopia IC (Gebremariam and Girma**,** 2019) and lower than the mean BW of 1.62 ±0.008kg and 1.98.81 ±0.009 kg at 20th week and at 40th week of age, respectively in IC of Belagaum division of Karnataka (Gowda *et al.,* 2020).The results are higher than 1.2 to 1.5kg found by Mahdabi *et al.* (2021).

Table 3: Effect of Ecotype and Sex on BW of Ethiopian IC Ecotypes

Source	df	Type III SSS	Mean Square	F value	Pr >F
Ecotype	5	1.10	0.22052261	2.86	0.0164
Sex	1	0.86	0.86057860	11.16	0.001
Ecotype x Sex	5	0.22	0.043919	0.57	0.72
Age	1	0.06	0.05666816	0.73	0.3925

The results in Table 3 show that there was significant effect of sex ($p<0.01$) and ecotype ($p<0.05$) on BW.

Association of SNPs on *BMPR1B, NPY, DRD2* and *Mel1C* genes with BW are shown in Table 4 and Figure 1. One SNP (rs13524270) of *BMPR1B* gene was significantly associated with BW (p-value=2.579). This is consistent with Awad *et al.* (2015) who found that A287G SNP of *BMPR-1B* gene was associated significantly with BW in Fayoumi and Rhodes Island Red chicken. Similarly, SNP rs15619223 on the same chromosome (GGA4) as *BMPR1B* located within the *LCORL* (ligand dependent nuclear receptor co repressor like) gene was found by Kudinov *et al.,* (2019) to be associated with BW. On the contrary, Niknafs *et al.* (2014)did not find association betweenA287G SNP in *BMPR-IB* genes with growth traits in chicken. Ashraf and El-Tarabany

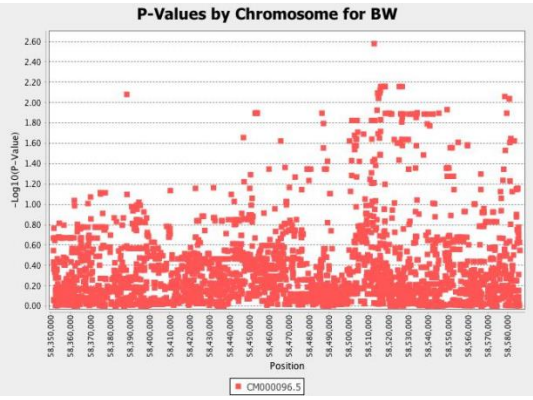
(2015) found that SNP of *BMPR-1B* was associated significantly with BW at 2nd to 8th weeks of age.

Table 4: Association of SNPs in the *BMPR1B, DRD2, NPY* and *Mel1C* Genes with Body Weight

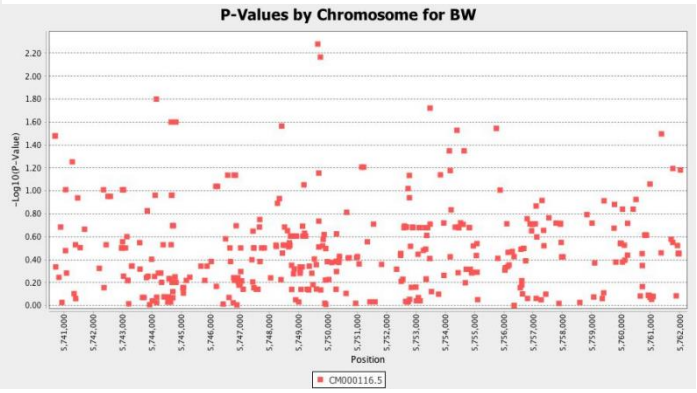
Gene	Chromosome	SNP ID	Position (bp[1])	-log10 (p-value)
NPY	2	SNP rs794226974	31466177	1.924
		SNP rs15938915	31468651	1.972
		SNP rs738097857	31468349	1.685
Mel1C	4	SNP rs734475748	17611346	3.219
		SNP rs317836677	17607428	2.92
		SNP rs315819466	17608023	2.92
DRD2	24	SNP rs313898728	5749656	2.28
		SNP rs732873238	5749750	2.166
BMPR1B	4	SNP rs13524270	58512841	2.579

Three SNPs (rs794226974, p-value=1.924; rs15938915, p-value= 1.972 and rs738097857, p-value =1.685) of *NPY* gene had significant association with BW (Table 3). This is consistent with Emrani *et al.,* (2017) who found that the GGaluGA142838 SNP located within *CCR4-NOT* transcription complex subunit 10(*CNOT10*) gene on GGA2 (*NPY* has been mapped on GGA2) was significantly associated with GW35, GW42 and GW49 traits. Another SNP GGaluGA141221 SNP, located on GGA2, was suggestively associated with BW42, BW49 and BW56 traits (Emrani *et al.,* 2017).*NPY* genes was found to be associated with growth traits in Mazandaran native chickens by Fatemi *et al.,* (2012). Rahman *et al.,* 2014) also found the CC genotypes female individuals of the *NPY* gene showed significantly higher better results for BW at day 50 than CT individuals of Silkie fowl birds.

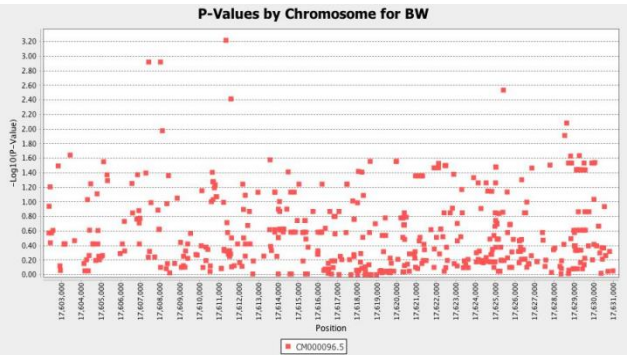
Figure 1: Manhattan Plots of Association of *BMPR1B*, *DRD2*, *NPY* and *Mel1C* Genes with BW of Ethiopian IC Ecotypes.



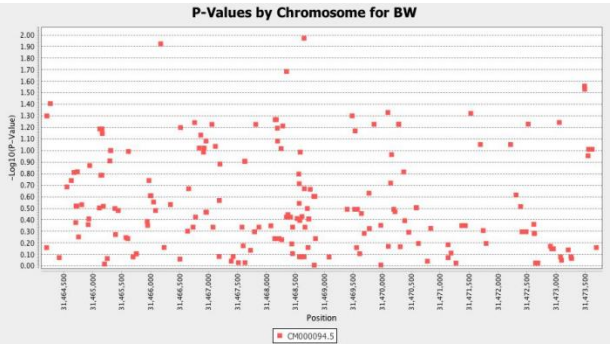
BMPR1B Gene(a),



DRD2 Gene(b)



MEL1C Gene(c)



NPY Gene(d)

The results of this study are inconsistent with Abdi *et al. (2014*) who did not find any significant association between 240 bp fragments from transcription starting site of the *NPY* gene with BW at 12 weeks of age in West Azerbaijan native poultry. Genotypes of the 240 bp amplicon of *NPY* gene with body weight traits (BW20, BW30, BW40) were found to be non-significant in Jabalpur colour and Kadaknath chicken (Padwar and Thakur, 2012). Three SNPs (SNP rs734475748, p-value=3.219, SNP rs317836677, p-value=2.92 and SNP rs315819466, p-value=2.92) of *Mel1C* gene were significantly associated with BW in the present study. Similarly, SNPJQ249896: g.294G>A) within melatonin receptor *Mel1C* was found to be significantly associated with body weight at first egg in local Iraqi chicken (BWM) (Al-Jaryan *et al.*, 2021). Two SNPs of *DRD2* gene (SNP rs313898728, p-value=2.28 and SNP rs732873238, p-value=2.166) were associated with BW in the present study. This is consistent with Rahman *et al.* (2014) in Silkie fowl birds when they found significant effect of dopamine D2 receptor gene on the BW at 50day in male.

4.0 Discussion

The results showed significant differences between sex and ecotype of individuals. These discrepancies could either be due to the variation in the age of the birds or were simply indicative of the negative effects of confined management on the performance of IC (Dana, 2010b).The mean BW found in this study was lower than one reported by Mbakaya *et al.*, (2022) in Rwanda IC and

Gebremariam and Girma**, (**2019**)** in Ethiopia IC. This could be due to both genetic and non-genetic factors (Jahan *et al.* (2017). The results are higher than 1.2 to 1.5kg found by Mahdabi *et al.* (2021). This could be due to better management, nutrition and difference in the genetic make-up of birds in the ecotypes studied (Gowda *et al.,* 2020). The mean BW of males and females varied significantly among the ecotypes, similar to one reported by Dana (2010b) in Mandura, Horro, Sheka Farta and Konso populations. The sexual dimorphism for BW could be due to the effect of male growth hormones actions resulting in different BW for male and female birds (Baeza *et al.,* 2001). This could be attributed to differences in gene expression of GH gene (Parsch and Ellegren, 2013).

This study focused on identifying SNPs within the *BMPR1B*, *DRD2*, *NPY* and *Mel1C* genes that are associated with BW. The findings reveal that 9 SNPs (*NPY*-3; *Mel1C*-3, *DRD2*-2 and *BMPR1B*-1) are associated with BW of Ethiopia IC ecotypes. These SNPs can be used as markers for improvement of BW in ICs. There could be more SNPs associated with BW. The present study used relatively small sample size which could have limited the statistical power needed to achieve significant associations (Lek *et al.,* 2018). Gene-mapping methods have been used to find the associations between the genotypes of individuals and the phenotypes of interest. Simple Mendelian traits that show discrete phenotypes are controlled by only a single or very few genes. But complex quantitative traits such as growth and body weight show continuous phenotypes. They are affected not only by many contributing loci across the genome that has usually small effects on the phenotype but also by environmental factors (Mackay *et al.,* 2009). These contributing loci have different magnitudes of genetic effects on traits. These genetic effects from different loci may be additive and contribute the most in phenotype expression. But in some other instances, some loci release their genetic effects only under the control of other genetic loci due to epitasis (Ahsan, 2014).

The present study confirmed a study by Habimana *et al.,* (2021) which suggested that GGA4 could harbors a gene with great effects on BW. The *Mel1C* and *BMPR1B* genes have been mapped on GGA4. Kanlisi *et al. (*2022) found a 75-Mb region on GGA4 which was significant for BW22 as it explained 19.7% of its genetic variance. Bora *et al.* (2023) genotyped *MEL1C* and found two genotypes AG and GG in the 'Zo-ar' chicken population. Chen *et al.* (2023) fed chicken with melatonin supplements; they asserted that melatonin presented inconsistent effects on livestock production, muscle/meat compositions and quality, which could be attributed to the divergence in animal type and/or supplement level of melatonin. In the study by Habimana *et al.,* (2021) a total of four significant SNPs (rs74098018, rs13792572, rs314702374, and rs14123335) significantly associated with BW were identified on chromosomes 8, 11, and 19 of Rwandese IC (Habimana *et al*., 2020). A 19-Mb window on chromosome 2 was found to explain 1.3% of the genetic variance of BW22 (Kanlisi *et al.* 2022). A region on chromosome 16 (2.34–2.66 Mb) was associated with both BW28 and BW42, and the most significant SNP in this region, AX_101003762, accounted for 7.6% of the genetic variance of BW28 (Li *et al.* 2021). A total of 266 loci mapped to GGA1, GGA4 and GGA27 were detected in spent hens at 72 weeks old (Maa *et al.,* 2019). A study by Emrani *et al*. (2017) showed that the Gga-rs15413679 on GGA3 had significant association with the BW77. The GGaluGA002276 SNP, which is located within *ubiquitin conjugating enzyme E2H* (*UBE2H*) gene on GGA1, was significantly associated with BW35, BW42 and BW49 traits. The marker Gga_rs14909475 on chromosome 1, had significant association with the BW35, BW84 and ADG28 traits. According to Rahman *et al.,* (2014), female individuals possessing CC genotypes of the *NPY* gene showed significantly high BW50 than CT individuals in Silkie Fowl

birds. Among the male birds, CT and TT individuals of the *NPY* gene had a better performance for body weight at day 50.

5.0 Conclusion

The results from the current study indicate that SNPs on *BMPR1B, NPY, DRD2* and *Mel1C* genes are associated with BW trait and are potential markers for use in molecular marker-assisted selection programs. More sophisticated experimental designs with large numbers of animals, including measurement of BW at various ages together with other putative candidate genes, are needed in order to establish the precise role of the four genes in practical breeding by means of marker assisted selection.

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Antimicrobials use by Smallholder Dairy Farmers in Peri-Urban Area of Nakuru Kenya: Knowledge, Attitudes and Practices

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Abstract

In dairy intensification, mastitis infections become prevalent and induce frequent Antimicrobial Use (AMU), sometimes inappropriately. This poses public health risks because of growing Antimicrobial Resistance (AMR). Stewardship programs informed by Knowledge, Attitude and Practices (KAPs) about AMU and AMR are necessary to halt or reverse their worrying trends. Data was obtained in cross sectional survey conducted in four peri-urban wards of Nakuru city in Kenya. Randomly selected sample farmers (n=124) with free-grazing, semi-zero-grazing and zero-grazing dairy management, representing increasing dairy intensification levels provided data on KAPs. Chi-square test statistics was fitted to establish associations between KAPs and dairy intensification levels. Results revealed that six in ten farmers (58.8 percent) had intensified dairy production; at least six in ten marketed their milk through informal outlets and were using antimicrobial drugs. Compliance with the withdrawal period was high and increased with ($p<0.05$) increasing intensification level. During the antibiotic withdrawal period, at least seven in ten farmers did not sell milk, fewer than four in ten consumed their milk at home and fewer than three in ten fed their milk to calves. Though independent of dairy intensification level ($p>0.05$), using antimicrobials for mastitis treatment increased while sourcing information on antimicrobial use from extension and veterinary officers decreased, with increasing intensification level. Farmers with some training on prudent antimicrobial use and with positive attitudes that milk from antimicrobial treated cows is unsafe, antimicrobial resistant pathogens and residues can be passed from milk to humans, mastitis can be treated without antimicrobial drugs, and that antimicrobial residues can end up accumulating in the soils increased ($p>0.05$) with increasing dairy intensification level. These results show that farmers knowledgeable and with positive attitudes and practices increased with increasing intensification of dairy management. The implication is that intensification of dairy management motivates farmers to improve their knowledge, positive attitudes and practices towards prudent use of antimicrobials in livestock. However, room exist for further targeted training and sensitization of farmers on the prudent and responsible antimicrobial use to foster stewardship.

Keywords: Antimicrobial Resistance, Antimicrobial Use, Kenya, Knowledge Attitude and Practices, Mastitis,

1.0 Introduction

Growing consumption demand for animal protein is driving intensification of livestock production systems in which antimicrobial use (AMU) is projected to increase by 67 percent between the year 2010 and 2030 (Gemeda *et al.,* 2020). In intensive dairy production, mastitis disease is prevalent and induces overdosing, under dosing or inappropriate use of veterinary antimicrobial drugs for treatment (Dankar *et al.,* 2023). Consequential to this is occurrence of antimicrobial residue in food of animal origin and subsequent development of antimicrobial resistance (AMR), with impacts on food safety and public health (Sulis *et al.,* 2022). These present public health risks because of a high probability of future treatment failures in both animals and humans. This public health concern is growing in countries where growth in consumption demand for animal protein is more rapid, yet consumption of antimicrobial veterinary drugs (AMD) is weakly regulated.

The growing public health concerns on AMU and AMR justifies antimicrobial stewardship programs. Effective antimicrobial stewardship programs are evidence-informed with the Knowledge, Attitudes and Practice (KAPs) regarding AMU of the farmers. This is a critical step in developing antimicrobial stewardship programs (Hassan, 2022). The 2021–2025 action plan of the Food and Agriculture Organization of the United Nations (FAO) has proposed antimicrobial stewardship program actions. These include boosting stakeholder engagement and awareness, enhancing research and surveillance, encouraging good practices, and strengthening governance and sustainable resource allocation (FAO, 2021). However, instance of inappropriate AMU frequently arises, which poses public health risks. This is a likely situation among the peri-urban smallholder dairy farmers in Kenya. The are intensifying their dairy production systems and so are more likely to engage in high AMU in treating mastitis infections, a prevalent intensification disease (Geta & Kibret, 2021). However, there is a dearth of information on KAPs regarding AMU and AMR among peri-urban smallholder dairy farmers, particularly in Kenya, a country with well-developed dairy industry in Africa (JKUAT, 2020), (Okello *et al.,* 2021).This knowledge gap is a barrier to evidence informed antimicrobial stewardship program actions that can reverse the trends in antimicrobial resistance development (Hassan *et al.,* 2021). The goal of responsible antimicrobial stewardship is to prevent the emergence and spread of antimicrobial resistance, maintain the effectiveness of veterinary drugs, and promote a One-Health concept (Sweeney *et al.,* 2024). Antimicrobial stewardship program actions are being implemented in industrial livestock systems because data is available from effective monitoring of AMU and AMR trends in livestock production (Gemeda *et al.,* 2020). In order to track the susceptibility of the principal mastitis pathogens to antimicrobial medications used to treat the disease in North America, mastitis pathogen antimicrobial susceptibility surveillance program was established and continues to implemented a in 2002 (Sweeney *et al.,* 2024). This is yet to be achieved in peri-urban smallholder dairy systems in Kenya because data on KAPs regarding AMU and AMR remain scarce. This knowledge gap hinders good understanding of the association between dairy intensification and KAPs about AMU and AMR. Therefore, this study assessed Knowledge, Attitudes and Practices related to antimicrobial use in different dairy production systems representing increasing intensification levels (free-, semi-zero and zero-grazing) among smallholder dairy farmers in Nakuru peri-urban areas of Kenya.

2.0 Materials and Method

2.1 Study Area

The study was conducted in peri-urban area of Nakuru city, specifically smallholder farms in Njoro, Lare, Lanet and Kabatini Wards. The area is located within Longitudes 35.41 º East or 35 º 24' 36" East and 36.6 ºEast or 36 º36' 0" East and Latitude 0.23 º North or 0 º 13' 48" North and 1.16 º South or 1º 9`36" South (Figure1). Dairy production under mixed farming dominates in these Wards, deeply rooted in White Settler farming heritage (Bebe et al., 2003). Dairy production is a major productive economic activity, with developed supportive infrastructure. The supportive infrastructure includes education, training and research institutions and facilities, milk processing, feed manufacture and veterinary investigation laboratories. These institutions are under public, farmer or private operation ownership (County Government of Nakuru Integrated Development Plan, 2018).

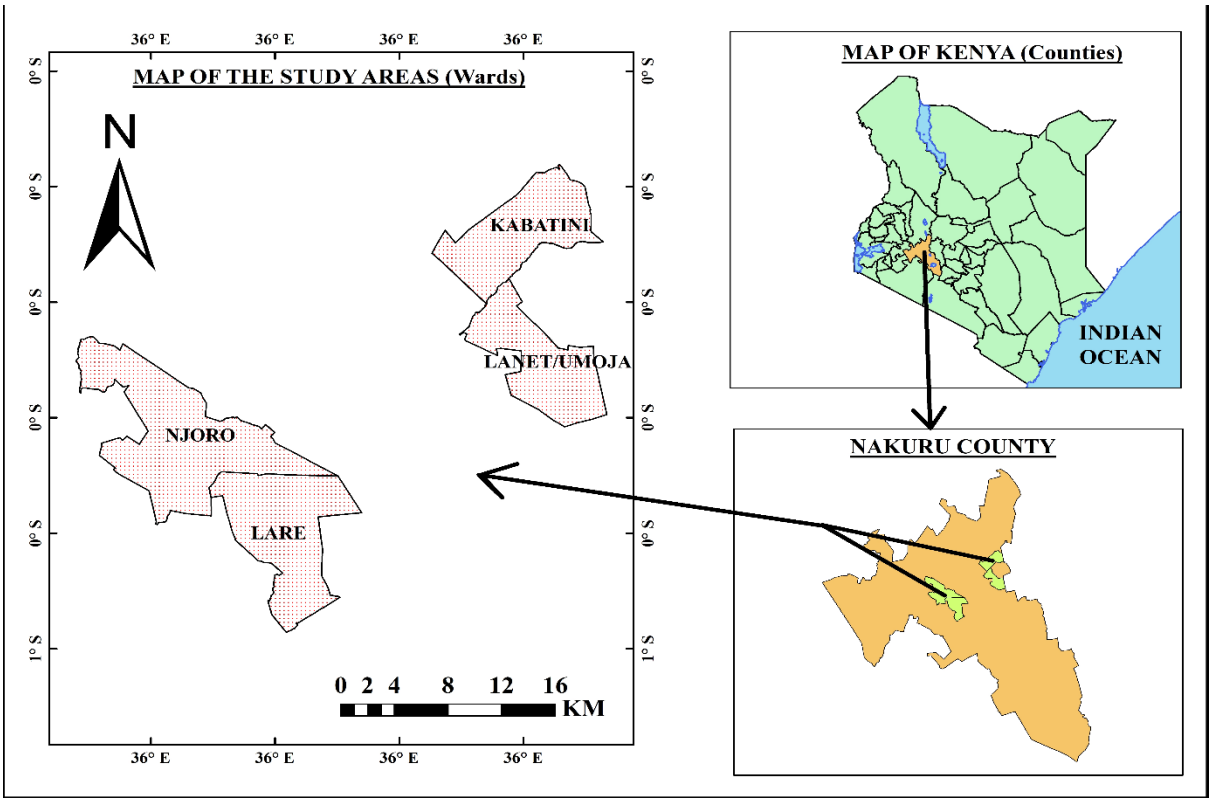

Figure 9:Map of the study area.

Source: Self

2.2Data collection

A structured questionnaire was developed in Kobo tool kit with four sections. The first section captured demographical information, the second section captured farmers' knowledge, the third section captured farmers' attitudes, and the last section captured practices by farmers about antimicrobial use, antimicrobial drugs and antimicrobial resistance. The interest on farmers' knowledgebase was to establish the purpose of using antimicrobial, whether antimicrobials are used for mastitis treatment and the recommended withdrawal periods are observed, and how

farmers source information on antimicrobial residues and antimicrobial resistance. The interest on farmers' attitudes was assessed with nine questions for the degree of agreement or disagreement to reveal positive and negative attitudes that farmers have about antimicrobial use on animals and humans. The interest on practices that farmers deploy in using antimicrobials was to gain insight into how farmers prudently used the antimicrobials. The questionnaire was pretested among 10 dairy farmers outside the four wards targeted for the study. Pre-testing was done to enhance the clarity and accuracy of the questions so that the intended information could be obtained. The adjusted questionnaire was administered to a random sample of 124 farmers who provided information on their KAPs regarding antimicrobial use, antimicrobial drugs and antimicrobial resistance.

2.3 Data analysis

Data in the Kobo tool kit was exported to Excel version 2016 for cleaning then processed for further descriptive and inferential statistics using SAS version 9.3 software. The descriptive and inferential statistics were generated by applying cross tabulation and Chi square test statistics for association between KAPs and dairy intensification level. Rejection of the null hypothesis of independence between KAPs and dairy intensification levels was set to $p< 0.05$. In analysing the sampling distribution, Pearson's Chi square was used when the expected frequencies in each cell were greater than five; otherwise Fisher's exact test probability was used when the expected frequencies were less than five.

3 Results

3.1 Demographic characteristics of sample farmers

Demographic characteristics of the sample farmers (n=124) is presented in Table 1. The demographic statistics reveal that more than 70 percent of the sample farmers came from two neighbouring wards (Njoro and Lare). Among the farmers, male (56.5 percent; 70/124) dominated over female (43.5 percent; 54/124), and seven in ten (70.2 percent) had attained at least secondary level education. Observed frequencies show that six in ten (58.8 percent) of the farmers had intensified dairy production management by adopting semi-zero-grazing or complete zero dairy management grazing. Though being in peri-urban area of the city is expected to present proximity advantage to formal market channels to these farmers, it is found that at least six in ten (63.7 percent) were marketing milk through informal market outlets.

Table 8: ***Demographic statistics of the sample farmers***

Categories	Frequency	Percent
Wards		
Njoro	50	40.3
Lare	40	32.3
Lanet	17	13.7
Kabatini	17	13.7
Sex		
Male	70	56.5
Female	54	43.5
Education Level		
Adult Education	4	3.2
Primary	33	26.6
Secondary	59	47.6
Post-secondary	28	22.6
Production System		
Free Grazing	51	41.1
Semi Grazing	33	26.6
Zero Grazing	40	32.2
Milk market outlets		
Informal only	79	63.7
Both formal and informal	36	29.0
Formal only	9	7.3

3.2 Farmers' knowledge about antimicrobial use

Summary statistics of farmers' knowledge about antimicrobial use is presented in Table 2. Use of milk before end of withdrawal period was associated with dairy intensification levels ($p<0.05$) as those selling milk decreased while those feeding milk to calves increased with increasing intensification levels. Before withdrawal period ended, farmer selling the milk decreased (15.7, 12.1, 0.0 percent) while those feeding milk to calves increased (9.8, 21.2 and 25.0 percent) in free, semi- and zero-grazing farmers, respectively. In overall, compliance with the recommended withdrawal period was high, with at least seven in ten farmers not selling such milk during the withdrawal period while less than four in ten consumed such milk at home. Regardless of dairy intensification levels, up to four in ten (21.1 to 37.3 percent) farmers did not use antimicrobials. Though reasons for using antimicrobials were independent of ($p>0.05$) of dairy intensification levels, use of antimicrobials for treatment (33.3 to 40.0 percent) and for treating mastitis (19.6 to 40.0 percent) had a pattern of increasing with increasing intensification levels from free to zero-grazing. When frequently using antimicrobials, the reason was treatment (30 to 40 percent) or production (22 to 42 percent) and not disease prevention (4 to 6 percent). Among the sample farmers, sourcing of information about antimicrobial use was independent ($p>0.05$) of their dairy intensification levels. However, those sourcing information from the extension and veterinary officers had a pattern of decreasing with increasing intensification levels from free- and semi-zero grazing (66.7 -68.6 percent) to zero-grazing (47.5 percent).

Table 9: ***Association between farmers' antimicrobial use knowledge and dairy intensification levels***

Question	Free grazing (n=51)	Semi grazing (n=33)	Zero grazing (n=40)	Chi-square test
Purpose of using antimicrobial (Percent)				*p=0.5110**
Do not use	37.3	21.2	32.5	
Treatment	33.3	30.3	40.0	
Prevention	3.9	6.1	5.0	
Production	25.5	42.4	22.5	
Using antimicrobials for mastitis treatment (Percent)				*p*=0.1939
Do not use	43.1	39.4	25.0	
Use sometimes	37.3	27.3	35.0	
Use frequently	19.6	33.3	40.0	
Using milk from antimicrobial treated cows before end of withdrawal period (percent)				*p*= 0.0405*
Home consumption	3.9	0.0	2.5	
do not sale out	70.6	66.7	72.5	
Sell out	15.7	12.1	0.0	
Give to calves	9.8	21.2	25.0	
Sourcing information on antimicrobial residues in food and antimicrobial resistance (Percent)				*p*= 0.0655*
No	21.6	30.3	25.0	
Extension/ veterinary officers	68.6	66.7	47.5	
Fellow farmers, relatives	2.0	0.0	5	
Field days	0.0	3.0	7.5	
Media (radio, newspapers, TV)	7.8	0.0	15	

***p* value from Fisher's exact test**

3.3 Farmers' attitudes towards antimicrobial use in dairy farming

The study identified the specific recommendations for antimicrobial use in animals and humans that farmers have positive and negative attitudes towards. Agreement with statement of recommendations for antimicrobial use indicated positive attitude. The observed frequency statistics for which the association with dairy intensification levels was significant ($p<0.05$) are presented in Table 3.

Overall, farmers with positive attitude towards AMU recommendations increased with increasing dairy intensification levels. Farmers with the attitude that milk from antimicrobial treated cows is unsafe to human health increased from those practicing free-grazing (56.9 percent) through semi-zero-grazing (78.8 percent) to zero-grazing (82.5 percent). Also, farmers with the attitude that antimicrobial resistant pathogens and residue from milk can be passed to humans through the food chain increased from those practicing free-grazing (60.8 percent) through semi-zero-grazing (69.7 percent) to zero-grazing (70.0 percent). Further, it was found that more of farmers practicing zero-

grazing (70.0 percent) than those practicing free-grazing (62.8 percent) had the attitude that mastitis can be treated without antimicrobial drugs. Similarly, more of farmers practicing zero-grazing (70.0 percent) than those practicing free-grazing (66.7 percent) had the attitude that antimicrobial residues can end up accumulating in the soils.

Table 10: Significant associations between farmers' attitudes towards antimicrobial use and dairy intensification levels

Production systems	Degree of agreement or disagreement (Percent)			Chi-square test
	Agree	Neutral	disagree	
Mastitis can be treated without using antimicrobial drugs				*P*=0.0010
Free (n=51)	62.8	23.5	13.7	
Semi (n=33)	24.2	39.4	36.4	
Zero (n=40)	70.0	12.5	17.5	
Milk from antimicrobial treated cows is harmful to human health				P=0.0283*
Free (n=51)	56.9	35.3	7.8	
Semi (n=33)	78.8	21.2	0.0	
Zero (n=40)	82.5	17.5	0.0	
Antimicrobial residues can end up accumulating in the soils				P=0.0004
Free (n=51)	66.7	25.5	7.8	
Semi (n=33)	51.5	12.1	36.4	
Zero (n=40)	70.0	36.4	2.5	
Antimicrobial resistant pathogens and residue from milk can be passed to humans through the food chain				*P*=0.0089*
Free (n=51)	60.8	37.3	2.0	
Semi (n=33)	69.7	12.1	18.2	
Zero (n=40)	70.0	27.5	2.5	

p value from Fisher's exact test

The observed frequency statistics for farmer attitudes towards antimicrobial use recommendations which showed no association with dairy intensification levels ($p>0.05$) are presented in Table 4. Farmer attitudes that were independent of their dairy intensification levels were whether any antimicrobial drug can be used to treat a lactating cow, withdrawal period should be observed to avoid antimicrobial drug residues in milk, relationship exists between antimicrobial use and antimicrobial resistance, and whether antimicrobial drug residues and drug resistance occurs when AMU is not prudent. Though independent of the dairy intensification levels also, farmers with the attitude that sale and distribution of antimicrobial drugs be restricted to licensed persons had a pattern of increasing with increasing intensification levels. The proportion of farmers increased

from free-grazing (58.8 percent) through semi-zero-grazing (63.6 percent) to zero-grazing (67.5 percent).

Table 11: Insignificant associations between farmers' attitudes towards antimicrobial use and dairy intensification levels

Production systems	Degree of agreement or disagreement (Percent)			Chi-square test
	Agree	neutral	disagree	
Any antimicrobial drug can be used to treat a lactating cow				*P=0.3076**
Free (n=51)	70.6	25.5	3.9	
Semi (n=33)	54.6	30.3	15.2	
Zero (n=40)	72.5	20.0	7.5	
Withdrawal periods should be observed to avoid antimicrobial drug residues in milk				*P=0.8945**
Free (n=51)	70.6	21.6	7.8	
Semi (n=33)	69.7	21.1	9.1	
Zero (n=40)	62.5	30.0	7.5	
Relationship exists between antimicrobial use and antimicrobial resistance				*P=0.0524*
Free (n=51)	66.7	27.5	5.9	
Semi (n=33)	39.4	45.6	15.2	
Zero (n=40)	67.5	30.0	2.5	
Sale and distribution of antimicrobial drugs be restricted to licensed persons				*P=0.6918**
Free (n=51)	58.8	33.3	7.8	
Semi (n=33)	63.6	27.3	9.1	
Zero (n=40)	67.5	20.0	12.5	
Antimicrobial drug residues and drug resistance occurs when not prudently used				*P=0.7747**
Free (n=51)	72.6	19.6	7.8	
Semi (n=33)	60.6	24.2	15.2	
Zero (n=40)	65.0	22.5	12.5	

***p value from Fisher's exact test**

3.4 Farmer practices in administration and prescription of antimicrobial drugs

Table 5 presents the observed association between farmers' practices (in the administration and prescription of antimicrobial drugs) and dairy intensification levels. Regardless of their dairy intensification levels, at least seven in ten farmers had professional prescription by veterinarians or pharmacy, observed withdrawal period and had been trained in antimicrobial use including residual effects and development of antimicrobial resistance. Farmers who self-prescribed and administered antimicrobial drugs declined ($p<0.05$) with increasing intensification of dairy management from free- to zero-grazing. Farmers who had most intensified their dairy management (zero-grazing) were the majority with some training on prudent antimicrobial use (87.5 percent) and in observing the withdrawal period (97.5 percent). There were several of farmers' practices in administration and prescription of antimicrobial drugs that were independent ($p>0.05$) of the dairy

intensification levels. These include where farmers were buying the antimicrobial drugs, how often they called a veterinarian whenever an animal is sick, and common disease condition(s) of lactating cows for which they administered antimicrobial drugs. Other practices were administering a follow up dose, stopping treatment when an animal recovers, checking for the expiry date before use, and using human drugs on animals. Though was independent of dairy intensification levels, use of human drugs on animals was prevalent (over 60.0 percent).

Table 12: Association between farmers' practices (in the administration and prescription of antimicrobial drugs) and dairy intensification levels

Question	Free grazing (n=51)	Semi grazing (n=33)	Zero grazing (n=40)	Chi-square test
From where do you usually buy the antimicrobial drugs? (Percent)				P= 0.1230*
Extension/veterinary officer	80.4	81.8	85.0	
Pharmacy	5.9	18.1	12.5	
Fellow farmers	13.7	0.0	2.5	
Who often prescribes antimicrobial drugs for you? (Percent)				P= 0.0124*
Extension/veterinary officer	63.6	97.0	85.0	
Pharmacy	5.8	0.0	5.0	
Self	25.5	3.0	10.0	
Who administers antimicrobial drugs to your animals? (Percent)				P = 0.0040*
Extension/veterinary officer	66.7	97.0	67.5	
Fellow farmers	11.8	0.0	5.0	
Self	21.6	3.0	27.5	
How often do you call a veterinarian whenever an animal is sick? (Percent)				P= 0.0524*
Frequently	27.5	42.4	45.0	
Sometimes	51.0	48.5	52.5	
Do not	21.6	9.1	2.5	
What is the common disease condition(s) of lactating cows for which you administer antimicrobial drugs? (Percent)				P= 0.4051*
Mastitis	11.8	24.2	35.0	
Respiratory diseases	17.7	12.1	10.0	
Diarrhoea	27.5	21.2	20.0	
Udder injuries	7.8	12.1	10.0	
Others	35.3	30.3	25.0	
Do you observe the withdrawal period after treating the animals with antimicrobials (Percent)				P= 0.0316*

Yes	86.3	78.8	97.5	
No	13.7	21.2	2.5	
Do you give subsequent doses after the administration of the first dose of the treatment. (Percent)				P= 0.4861
Yes	72.6	72.7	82.5	
No	27.5	27.3	17.5	
Do you stop giving treatment when an animal recovers? (Percent)				P= 0.5867
Yes	72.6	66.7	77.5	
No	27.5	33.3	22.5	
Have you had training on antimicrobial usage, AMR, and residue. (Percent)				p= 0.0221
Yes	68.6	60.6	87.5	
No	31.4	39.4	12.5	
Do you check for the expiry date before AMU (Percent)				P= 0.0737
Yes	82.4	66.7	87.5	
No	17.7	33.3	12.5	
Do you use human drugs on animals. (Percent)				P= 0.5034
Yes	66.7	54.6	65.0	
No	33.3	45.5	35.0	

***p value from Fisher's exact test**

4.0 Discussion

The distribution of farmers with free-, semi-zero and zero-grazing dairy management observed in this study support that intensification of dairy management is increasing in the peri-urban areas of Nakuru city. Though more than half of the sample farmers (58.8 percent) had intensified their dairy management, a larger majority marketed milk in the informal market outlets. Participation in the informal milk market outlets is likely a weak link in implementing antimicrobial stewardship programs, boosting stakeholder engagement and awareness, enhancing research and surveillance, encouraging good practices, and strengthening governance and sustainable resource allocation (FAO, 2021).

This study reported that seven of ten farmers at least had secondary education. Training farmers to enhance disease detection accuracy is vital for antimicrobial stewardships program. However, achieving lasting progress will necessitate a comprehensive approach(Habing & Pereira, 2024). A higher level of education among dairy farmers and farm workers can play a significant role in promoting AMU stewardship practices. Better-educated individuals are more likely to understand the importance of prudent antimicrobial use, follow recommended guidelines, implement bio security measures, and adopt best management practices. Education can also enhance their ability to interpret diagnostic test results, maintain accurate treatment records, and make informed decisions about antimicrobial therapy. Consequently, increased education levels can encourage more responsible and sustainable AMU stewardship actions as dairy farming intensifies.

Regardless of the level of dairy intensification management, the study revealed that at least seven out of ten farmers were utilizing antimicrobial drugs, with up to eight out of ten employing these drugs specifically for the treatment of mastitis. This finding is not surprising, as mastitis is a highly prevalent infection in intensified dairy management among smallholder farmers (Abdi *et al.*, 2021). The observed therapeutic use of antimicrobials is consistent with the observations of many researchers. Gemeda *et al.* (2020), Farrell *et al.* (2021), Geta & Kibret (2021), and Hassan (2022) have all reported that antimicrobials are predominantly used for therapeutic purposes in livestock production systems. However, other researchers have reported contrasting observations, suggesting that the primary use of antimicrobials is for disease prevention rather than treatment. Nyokabi *et al.* (2021), Omwenga *et al.* (2021), Mogotu *et al.* (2022), and Kisoo *et al.* (2023) are among the researchers who have highlighted the preventive use of antimicrobials as a common practice in various livestock production settings. This discrepancy in findings may be attributed to regional differences, variations in production systems, or the specific contexts in which the studies were conducted. It is crucial to investigate the underlying factors contributing to the contrasting observations and tailor interventions accordingly to promote judicious antimicrobial use practices. The high prevalence of mastitis and the associated therapeutic use of antimicrobials observed in the present study underscore the need for effective disease management strategies and alternative approaches to minimize the reliance on antimicrobial treatments. Improved hygiene practices, vaccination programs, and the adoption of preventive measures could contribute to reducing the incidence of mastitis and, consequently, the need for antimicrobial therapy. Ongoing research, education, and collaboration among stakeholders, including farmers, veterinarians, and policymakers, are essential to address the challenges of antimicrobial resistance and promote sustainable livestock production practices.

The present study revealed a high level of compliance with the withdrawal period among farmers, which refers to the mandated time after administering antimicrobials to dairy animals before their milk can be introduced into the food chain. Notably, this compliance increased significantly ($p<0.05$) as the level of dairy intensification increases. Specifically, during the antimicrobial withdrawal period, at least seven out of ten farmers refrained from selling the milk, fewer than four out of ten consumed the milk at home, and fewer than three out of ten fed the milk to calves. These findings align with the recommendations of Uyama *et al.* (2022), who emphasized the importance of adhering to withdrawal periods to prevent antimicrobial residues from entering the food supply and safeguard public health. Their study highlighted the potential risks associated with the consumption of milk containing antimicrobials residues, including the development of antimicrobial resistance and adverse health effects. Similarly, Asaah Ndambi *et al.* (2022) reported a positive correlation between farmer knowledge of withdrawal periods and compliance with these guidelines in their study conducted in Cameroon. They stressed the need for continuous education and awareness campaigns to promote responsible antimicrobial stewardship practices among dairy farmers. The observed trend of increased compliance with withdrawal periods as dairy operations intensified could be attributed to factors such as improved access to veterinary services, better record-keeping, and enhanced awareness of food safety and public health concerns, as suggested by Kashongwe *et al.* (2020) in their study on antimicrobial use practices in intensive dairy farming systems. However, it is concerning that a significant proportion of farmers still engaged in practices such as consuming or feeding milk to calves during the withdrawal period. These practices can contribute to the spread of antimicrobial resistance and pose potential health risks, as highlighted by Uyama *et al.* (2022) and Asaah Ndambi *et al.* (2022). Continued efforts are needed to address these practices through targeted education and extension programs, as

recommended by organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO). These initiatives should emphasize the importance of strict adherence to withdrawal periods and promote alternative management strategies to minimize the need for antimicrobial treatment, ensuring food safety and public health throughout the dairy production chain (WHO, 2015; FAO, 2021).

The study revealed that although independent of the level of dairy intensification ($p>0.05$), there was an increasing trend in the use of antimicrobials for treating mastitis, while the practice of sourcing information on antimicrobial use from extension and veterinary officers decreased as dairy operations became more intensive. This finding contrasts with previous research that has emphasized the importance of veterinary guidance and extension services in promoting judicious antimicrobial use, particularly in intensive livestock production systems. For instance, Redding *et al.* (2014) highlighted the positive impact of veterinary-client relationships and education programs on reducing unnecessary antimicrobial use among dairy farmers in the United States. Similarly, a study by Higham *et al.* (2020) found that farmers who received training and support from extension services were more likely to adopt best practices for responsible antimicrobial stewardship, such as improved record-keeping and adherence to treatment protocols. The observed trend in the present study raises concerns about the potential for increased antimicrobial use and the risk of antimicrobial resistance as dairy operations intensifies, especially if farmers rely less on professional advice and guidance from veterinary and extension services. It is crucial to address this issue by strengthening the collaboration between farmers, veterinarians, and extension services, as recommended by the World Organisation for Animal Health (OIE) and the Food and Agriculture Organization of the United Nations (FAO) in their guidelines for prudent and responsible use of antimicrobials in agriculture (OIE, 2018; FAO, 2021). Ongoing education and awareness campaigns, coupled with accessible and affordable veterinary services, can play a vital role in promoting sustainable antimicrobial use practices, even as dairy production systems become more intensive.

The present study found that farmers who received training on prudent antimicrobial use and held positive attitudes regarding the risks associated with antimicrobial overuse were more likely to adopt responsible practices as dairy production intensified. Specifically, those who believed milk from antimicrobial-treated cows is unsafe for consumption, that antimicrobial-resistant pathogens and drug residues can transmit from milk to humans, that mastitis can be managed without antibiotics, and that antimicrobial residues accumulate in soil demonstrated an increased tendency ($p>0.05$) toward judicious use as their dairy operations became more intensive. These findings align with previous research highlighting the importance of farmer education and awareness. Higham *et al.* (2020) emphasized that understanding antimicrobial resistance risks and residue entry into the food chain positively shapes attitudes toward antimicrobial stewardship. Similarly, Redding *et al.* (2014) found U.S. dairy farmers receiving prudent use training were more likely to implement best practices like selective dry cow therapy to reduce unnecessary antimicrobial administration. Moreover, Saini *et al.* (2012) observed farmers recognizing antimicrobial residue risks in milk and the environment were more receptive to alternatives such as improved hygiene and preventive measures to minimize treatment needs. These findings underscore the pivotal role of education in promoting responsible antimicrobial stewardship, especially as dairy production intensification.

In the present study, it was observed that the majority of farmers obtained antimicrobial drugs through veterinarians, who not only prescribed but also administered the drugs themselves. This practice is considered beneficial and should be encouraged, promoted, and strengthened to mitigate concerns related to antimicrobial resistance (AMR) and contribute to the sustainable use of antimicrobials (Dankar *et al.,* 2022). This approach aligns with the Global Action Plan on AMR, which outlines strategies for combating the emergence and spread of AMR. The implementation of such strategies is a response to the threats posed by the emergence and spread of AMR to multiple Sustainable Development Goals, including those related to health, food security, environmental well-being, and socioeconomic factors (WHO *et al.,* 2019; FAO, 2021). By promoting the involvement of veterinary professionals in the procurement and administration of antimicrobial drugs, the study's findings support responsible antimicrobial stewardship practices. However, our findings deviate from those reported by Gemeda *et al*. (2020) in their study conducted in Ethiopia. The researchers observed that antimicrobial drugs were primarily accessed from private suppliers in the context of their study. It is important to note that their study sample focused on a pastoralist production system, which differs from the smallholder peri-urban dairy systems examined in our research. The contrasting findings could be attributed to the differences in production systems, as accessibility to veterinary services is often limited in pastoralist production settings. In our study, we did not observe a predominant reliance on private suppliers for antimicrobial drug procurement. This discrepancy with the findings of Gemeda *et al.* (2020) could potentially be explained by the variations in the production systems under investigation. Smallholder peri-urban dairy operations may have more readily available access to veterinary services and guidance compared to pastoralist systems, which could influence the sources from which antimicrobial drugs are obtained.

The observed practice of farmers obtaining antimicrobial drugs through veterinarians, who also prescribed and administered the drugs, can be attributed to the education and guidance received from veterinary extension officers on prudent antimicrobial use and the relationship between antimicrobial use (AMU) and antimicrobial resistance (AMR). This educational intervention by veterinary officials likely played a crucial role in shaping the responsible antimicrobial procurement and administration practices among the farmers in this study. However, this finding stands in contrast with a study conducted in Ethiopia by Geta & Kibret (2021), where farmers reportedly administered antimicrobial drugs to sick animals before seeking veterinary assistance. Furthermore, the same authors stated that farmers claimed they would continue to use antibiotics on animals even if they were aware of the potential negative impact on public health (Geta & Kibret, 2021). This unfortunate practice can be attributed to lack of education on prudent use of antimicrobials and the relationship between AMU and AMR by the veterinary officials from the private sector.

5.0 Conclusion

It can be concluded that farmers knowledgeable and with positive attitudes and practices increased with increasing intensification of dairy management. This indicates that intensification of dairy management somewhat motivates farmers to improve their knowledge, positive attitudes and practices towards prudent use of antimicrobials in livestock. However, room exists for further targeted training and sensitization of farmers on the prudent and responsible antimicrobial use to foster stewardship.

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The Effects of Treatment of *Prosopis juliflora* Leaves and Pods with Bentonite and Wood Ash on Feed Intake, Milk Production and Composition in Dairy Goats

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Abstract

The high tannin content in *Prosopis juliflora* leaves and pods (LP) has hindered its efficient usage as a leguminous tree forage despite its high nutritive value. Goats are capable of using it but in limited quantities, despite of being capable of meeting their nutritional requirements. Binders reduce and enhances feed intake and digestibility. An experiment was conducted to determine the impact of natural binders on intake, milk production, composition, and mineral content of dairy goats when used to treat *P. juliflora* LP. Twelve lactating Toggenburg breed dairy goats and their crosses weighing 35±2 kg, were used in the experiment. They were placed in four treatments in a randomized completely block design (RCBD) with the breed being the blocking factor. They were housed individually with three goats in each treatment. A digestibility trial was initially conducted to decide on the ratio of *P. juliflora* (LP) that was more digestible for the goats. Feed leftovers were collected every morning to determine intake, and the goats were milked in the morning and evening to determine milk production. At the end of the experiment, milk samples from every treatment were analyzed to determine milk composition and mineral content. The results showed that treatment not only improved intake but also milk production, composition, and mineral content.

Keywords: Bentonite, *in-vitro* digestibility, natural binders, tannins, wood ash

1. INTRODUCTION

Goats are found in almost all households. The poor man's cow has been credited for its ability to survive in almost all climatic conditions, better resistance to diseases, and its high feed conversion efficiency. Their high feed conversion capacity coupled with presence of proline in their saliva that act as an initial defence against tannins on consumption, enables them to utilize tannins better than cattle and sheep (Niezen *et al.,* 1995). *Prosopis juliflora*, a leguminous tree forage that does excellently in arid and semi-arid areas including those receiving rainfall as low as 100mm per annum can be utilized by goats (Haregeweyn *et al.,* 2013). However, the inclusion of *Prosopis juliflora* in the diet is limited to 30% due to its high antinutritional factors and effect on teeth (Mutavi, 2020).

This study focused on contributing to enhanced usage of the forage by reduction of the ant nutritional factors, particularly tannins using wood ash and bentonite as binders. These binders are highly effective in tannin reduction and enhancement of feed intake and digestibility. Natural binders have no adverse effect on the environment unlike synthetic binders like polyethylene glycol (PEG) and polyvinylpyrrolidone (PVP) whose intensity in affecting the environment is barely known. Moreover, they are locally available and affordable, and has been used since time immemorial in softening vegetables. Bentonite has been reported to be as effective as PEG, and it is also applied at a lower quantity of 20 g/kg (Kemboi *et al.,* 2022). More than 90% of Kenyans

rely on either charcoal or wood for cooking, and 6-10% of this is converted to wood ash (AL-Kharabsheh *et al.,* 2022; Bailis *et al.,* 2020). According to Mlambo *et al.* 2004, wood ash can reduce 75% and 96% of tannins in *A. nilotica* and *D. cineraria* fruits respectively.
An experiment was carried out to determine the effect of the treatment of *P. juliflora* LP with wood ash, bentonite, and synergistically on feed intake, milk production, and milk quality of the Toggenburg dairy goats. It aimed at enhancing the usage, adoption, and appreciation of *P. juliflora* as an alternative protein source. According to Azani *et al.* 2017, *P. juliflora* can meet the nutritional requirements of lactating dairy goats of 17% crude protein.

2. MATERIALS AND METHODS

2.1 Study site

The study was carried out at Tatton Agriculture Park (TAP) of Egerton University's main campus which is situated in Njoro sub-county, Nakuru county, Kenya. It is at 0° 23 S, 35° 55 N with an altitude of 2,238 m above sea level. The latitudes and longitudes are 0.369734°S and 35.932779°E respectively. The average annual rainfall ranges from 900-1,200 mm with average daily temperatures of 17°C-22°C [8].

2.2 Collection and Preparation of feeding materials

Mature leaves and pods used in this study were sourced from Marigat Sub-County, Baringo County, which is 0° 20'N and 35° 37'E. The collection was carried out during the dry months of December and January. Marigat is approximately 20 Km from both Lake Baringo and Bogoria Kenya, and lies 1,080 m above sea level. It receives rainfall of 700 – 950 mm per year with peaks in April/May and July/August but usually erratic (Baringo County Government, 2022). The collected leaves and pods were transported to Egerton University where they were assorted by removing green pods and spoilt and mouldy leaves and pods. They were then spread out for efficient drying. Bentonite was mixed with the feed at the rate of 20 g/kg, and wood ash collected mixed thoroughly, sieved to remove foreign particles, and used at 400 g/L of water while avoiding kerosene-tainted wood ash.

2.3 Experimental animals and design

Eight pure Toggenburg breeds and their four crosses were sourced from TAP and used in this study.The goats were lactating, healthy and weighed 35±2 kg.. . The goats were arranged in a randomized completely block design(RCBD) with a cross in each treatment. They were housed individually with feed troughs, watering cans, and salt licks. They were given fourteen days' adaptation period before data collection.

2.4 Experimental diets and feeding

Rhodes grass hay sourced from a local supplier was used as the basal diet. They were ground to pass through a 4 mm sieve. The goats were also provided with a mineral supplement in form of a salt lick and water *ad-libitum.* The four diets were decided upon after an *in-vitro* digestibility trial that was carried out earlier on *P. juliflora* leaves and pods, where 75% leaves mixed with 25% pods were found to be the most digestible. This was used as the supplement at 30% of the diet in all the treatments. The dietary treatments were as follows: -
T1) - Rhodes grass hay (*ad-libitum*) plus 75:25 ratios of *P. juliflora* LP (control)
T2- Rhodes grass hay (*ad-libitum*) plus wood ash treated 75:25 ratios of *P. juliflora* LP
T3- Rhodes grass hay (*ad-libitum*) plus bentonite treated 75:25 ratios of *P. juliflora* LP

T4- Rhodes grass hay (*ad-libitum*) plus 75:25 ratios of *P. juliflora* LP treated with a 50:50 ratio combination of wood ash and bentonite

2.5 Data collection

Data collection was carried out for eighth week with a 14-day adaptation period. The supplements and the treatments were mixed thoroughly and left overnight before being fed in the morning just after milking. They were given two hours with the supplement before the basal diet, given *ad-libitum,* was introduced. The goats were milked daily in the morning at 07:00 am and in the evening 04:00 pm, and the milk produced recorded. Feed refusals were collected just before milking and introduction of fresh feeds, then weighed and recorded. The animal handling procedures were approved and certified by the Ethical Clearance Committee, Egerton University, and permitted by the National Commission for Science and Innovation (NACOSTI), Kenya.

2.6 Milk analysis

During the last week of data collection, milk samples were retrieved from goats in all treatments and analyzed for fats, solids, proteins, lactose, salts, freezing point, and density using an Ultra scan milk analyzer.

2.7 Determination of minerals

Calcium, phosphorus, zinc, and iron content in milk of the four treatments were determined using the Atomic Absorption Spectrometer 3300 as was used by Perkin-Elmer, Massachusetts, USA. The milk samples were prepared according to Brooks, 1970, by precipitation of casein using trichloroacetic acid (TCA). The four minerals were decided upon based on the results of Balthazar *et al.* 2017, who categorizes minerals in goat milk with their solubility. According to these authors, zinc has 14% solubility while iron is 38% soluble. In the category of major minerals, calcium and phosphorus have the lower solubility compared to other major minerals at 32% and 38% respectively.

3. RESULTS

Dairy goats fed diets with untreated *P. juliflora* leaves and pods (control) performed worse than those fed with treated *P. juliflora* leaves and pods (**Table 1**). In terms of dry matter intake, there was no significant difference ($P>0.05$) between T1, T3, and T4, while there was no difference between T4, T3, and T2. However, T1 and T2 were different. There was no difference in milk production in all the treatments except for the control.

Table 1: Average daily dry matter intake and milk production of dairy goats fed Rhodes grass hay and supplemented with treated and untreated *Prosopis juliflora* leaves and pods

Treatments	Total DMI (kg)	Milk Production (ml)
Control (T1)	1.90[b]	108.02[b]
Wood ash treated (T2)	2.01[a]	137.67[a]
Bentonite treated (T3)	1.96[ab]	124.26[a]
Wood ash and Bentonite treated (T4)	1.94[ab]	123.89[a]
SEM	0.01	2.07
p-value	0.0021	< .0001

[a, b] *Means within a column with different superscripts differ significantly at P<0.05*., DMI=dry matter intake

Milk sourced from dairy goats fed diets with untreated *P. juliflora* leaves and pods (T1) was low in all parameters (**Table 2**). Wood ash (T2) and bentonite treated (T3) had similar fat contents, solids, density, and salts while solids, freezing points, proteins, and lactose contents were similar in all treatments except T1. T1 and 50:50 wood ash and bentonite (T4) had similar amounts of salts.

Table 2: Comparison of various parameters of milk composition of the treatments

Parameters	T1	T2	T3	T4	SEM	*p*-value
Fats (%)	2.30[c]	5.20[b]	6.15[b]	8.70[a]	0.33	0.0001
SNF (%)	6.45[b]	9.55[a]	9.60[a]	8.35[a]	0.37	0.0009
Density (g/l)	1021.98[c]	1032.02[a]	1032.55[a]	1026.65[b]	0.4	0.0001
Freezing point (°C)	0.41[b]	0.65[a]	0.66[a]	0.59[a]	0.03	0.0007
Protein (%)	2.40[b]	3.60[a]	3.65[a]	3.30[a]	0.14	0.0009
Lactose (%)	3.60[b]	5.40[a]	5.45[a]	4.70[a]	0.21	0.0009
Salts (%)	0.45[b]	0.75[a]	0.70[a]	0.48[b]	0.03	0.0002

[a, b, c] *Means within a row with different superscripts differ significantly at P<0.05;* SNF=Solids-Non-Fat

Treatment 3 had the highest amounts of iron, while other treatments had equal amounts (**Table 3**). Treatment 3 and 4 had similar and highest amounts of calcium while T1 had the lowest. T2 had the highest amount of zinc whereas the rest of the treatments had comparable amounts. Treatment 2 also had the highest similar amounts of phosphorus with T1 while T3 and T4 had equal amounts.

Table 3: Iron, Calcium, Zinc, and Phosphorus contents of the treatments

Parameters	T1	T2	T3	T4	SEM	*p*-value
Iron	13.85^{b}	18.08^{a}	12.12^{b}	11.15^{b}	0.7	0.0005
Calcium	0.32^{c}	2.30^{a}	1.98^{b}	2.16^{ab}	0.05	0.0001
Zinc	0.08^{b}	0.08^{b}	0.15^{a}	0.09^{b}	0.01	0.0015
Phosphorus	2.60^{ab}	2.45^{b}	2.86^{a}	2.38^{b}	0.07	0.0055

$^{a, b}$ *Means within a row with different superscripts differ significantly at P<0.05*

4. DISCUSSION

The results indicate that treatment with tannin binders enhanced feed intake. As much as there was no difference between T3 and T4 with the control, there was a difference between T2 and the control, and no difference between T2, T3, and T4. This makes wood ash more effective in enhancing feed intake as compared to other forms of treatment when used at 400 g/l. This is in agreement with the findings of Brown & Norris, 2016, that the more the amount of wood ash used, the better the results. This can be attributed to the fact that wood ash is alkaline and can be used to inhibit anti nutritional factors such as toxins in tannins in diets Van Ryssen, 2018.

Tannins not only interfere with the digestibility of feeds but also limit their palatability hence intake. Wood ash has been used in the treatment of sorghum grain, millet, vegetables, and the leaves of leguminous tree forages like *Acacia cyanophylla.* T1 might have performed the same as T3 and T4 because the ratio of leaves and pods in the diet can also be used to minimize the effect of tannins. According to Mueller-Harvey, 2006, mixtures can be applied to thwart the harmful effects of tannins. Salawu *et al*, 1999 also discovered that leaves of calliandra were affected when mixed with its leaves or pods. An *in-vitro* digestibility study that was conducted by Ouma *et al.* 2023, prior to this experiment also showed that wood ash at 400 g/l of water was more digestible than bentonite, and the ratio combination of leaves and pods also affected their digestibility.

Milk production was higher in all the treatments except the control. This could be because the ratio combination does not have as much effect on tannins as treatment with either wood ash, bentonite, or wood ash and bentonite at a 50:50 ratio combination. Henke, 2017 carried out research to determine the effect of quebracho tannin extract, a source of condensed tannins, on milk production in dairy cows among other factors, and found out that at high inclusion level, it had detrimental effects on not only milk production, but also diet digestibility, and general performance of the animals. This study shows the effects tannins have on milk production, with the treated diets generally performing better than the untreated control. In addition to that, with high tannin diets, there is reduced voluntary intake and animals tend to spend more time and energy ruminating due to the astringent factor that is formed as a result of the complexes formed with tannins and salivary proteins (Muir, 2011).

The results also show that the composition of milk sourced from goats in the treated diets was higher in all the parameters that were determined (fats, solids, density, freezing point, proteins,

lactose, and salts) than in the control. According to Nascimento, 2021, high tannin content in the diet reduce the productive efficiency of goats. In their study, high tannin content decreased the concentration of milk fat. This is also in agreement with the findings of Wang, 1996, that investigated the effect of condensed tannins present in *Lotus corniculatus* on the lactation performance of ewes.

Niezen *et al.* 1995, investigated the impact of condensed tannins on milk composition in angora goats and found out that they not only interfere with lactose content, lowering them, but also decrease the level of solids, solid-not fats and somatic cell count in milk. Tannins generally interfere with protein degradation in the rumen and increase rumen and intestinal protein by-pass by forming tannin-protein complexes which make the protein component of the feed unavailable to the animal (Mueller-Harvey, 2006). This can explain the lower protein component in milk. It can also explain the low freezing point, density, salts, and mineral contents (iron, calcium, zinc, and phosphorus) in the control. The density of the milk derived from the control diet was below the minimum and average in goats of 27 and 30 respectively. The high calcium content in a wood ash-treated diet can be attributed to the fact that calcium is the major mineral component in wood ash. According to Van Ryssen, 2018, the higher the calcium content in the diet, the lower the phosphorus content hence phosphorus deficiency in livestock. This can explain the lower phosphorus content in milk derived from goats-fed wood ash treated diets compared to bentonite treated.

CONCLUSION

It was concluded that lactating dairy goats fed diets supplemented with treated *P. juliflora* leaves and pods (75:25) performed better in terms of dry matter intake, milk production, as well as milk composition. Treatment with wood ash at the rate of 400 g/l had a higher positive impact on feed intake. Treatment with either wood ash, bentonite, or wood ash and bentonite (50:50) positively affected milk production, composition, and milk mineral content. Therefore, treatment with natural, and readily available binders (wood ash and bentonite) is effective in enhancing the performance of lactating dairy goatshence recommended for adoption to daity goat farmers

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Uganda's production potential of Black Soldier Fly larvae for use in pig diets: A mini-Review

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Abstract

Uganda's pork consumption has steadily grown over time and will follow the same trend even in the next two decades. However, the commonly used protein sources (silver fish and soybeans) for formulating pig diets in Uganda are expensive and are used as human food. The current review explores the potential of using Black Soldier Fly (BSF) larvae as an alternative protein source in pig diets. The review mainly delves into the potential of using the unexploited raw material base (organic wastes) to raise enough BSF larvae for sustaining Uganda's pig feed production. On an annual basis, the food wastes from Uganda's urban centres alone can produce enough BSF larvae for formulating pig diets that can feed the 4.4 million pigs in Uganda for over 5 months. Due to insufficient information on other wastes like animal manure and crop wastes from rural areas, it was extrapolated that the total annual organic waste production from all over the country could sustain raising BSF larvae for use in formulating pig feeds that can feed the 4.4 million pigs all year round, and even be extended to some other enterprises like poultry. This extrapolation was based on the assumption that all pigs in Uganda are intensively managed and fed on complete feeds formulated using BSF larvae as the protein source. In conclusion, Uganda can produce enough BSF larvae for feeding her pigs all year round, and can potentially sustain her future pork demand. There's need to sensitize the different stakeholders on the importance of using BSF larvae as an alternative protein source in pig diets.

Key words: Black soldier fly larvae; food waste; pig diets; pork; organic wastes

Introduction

Pig production is one of the fastest growing and most important sub-sectors in Uganda's agricultural economy (Mutua *et al.,* 2020). The hastened growth of Uganda's pig sub-sector stems from the high demand for pork in the country, with consumption of up to 3.4kg/capita (FAO, 2021). The projections by FAO (2017) indicate that Uganda's annual pork consumption will be up to 474,000 metric tonnes, by 2030 and will reach 1720,000 metric tonnes by 2050, which will be the highest in the region.

On the other hand, statistics on the future pig production, and the ability to sustain the projected demand, is scanty. Primarily, future increase in pig production will most likely be constrained by the persistently high feeding costs. For example, only 1.3% of the feeds needed in intensive pig production systems is produced annually, resulting in a deficit of almost 99% (Straub and

Vernooij, 2021). Most importantly, the key protein sources in pig diets are fish soya bean meals which are costly and also act as primary protein sources in human diets. Continued dependence on these ingredients as protein sources in pig diets may not sustain the efforts to produce enough pork to meet the projected demand.

In their review, Kasima *et al.* (2023) applauded several low-cost alternative protein sources for use in producing what they called "*high-quality pork.*" Among these, the black soldier fly larvae (BSFL) were the most outstanding as they reported them to be readily raised on organic materials. Several studies have also dwelt around the protein quality of BSFL and realised that BSFL meal can potentially substitute both soybean meal and fishmeal in pig diets (Hong and Kim, 2022; Chia *et al.,* 2021). Although much work has supported the use BSFL in pig diets due its high protein content, it is not yet clear whether Uganda has the potential to sustainably produce enough BSFL for use in pig diets. Establishing this potential is critical in guiding policy with regards to laying strategies for ensuring sustainable production of pig feeds. The current review, therefore, employs a prospective approach, with assumptions based on the current pig population in Uganda and availability of wastes, to model the potential of producing enough quantities of BSFL for use in pig feed production. The review has assumed an intensive operation where all pigs are fed on feeds formulated using BSFL meal as the main protein source with no free-ranging to augment the diets. The review has adopted the current population of pigs (4.4 million pigs) in Uganda (UBOS, 2020b) in estimating Uganda's potential to feed her pigs on diets comprising of BSFL meal as the protein source.

Use of Black Soldier Fly Larvae in pig diets

Using BSF larvae in pig diets has been widely studied and proven feasible and sustainable. The BSF larvae has attracted attention of animal nutritionists chiefly because of their high protein content ranging from 40% to 61% (Hong and Kim, 2022) and low-cost investment in raising them (DiGiacomo and Leury, 2019; Shumo *et al.,* 2019). Most importantly, BSF larvae have a higher (88%) ileal digestibility of Lysine, the most limiting amino acids in pig diets than fishmeal (86%) and is comparable to the 89% of soybean meal (Crosbie *et al.,* 2020). Consequently, BSF meal can better serve as a substitute to the other protein sources in pig diets without compromising performance of pigs.

Current state of BSF production and potential of sustaining pig production

Intensive livestock production systems are primarily dependent on imported feeds (Chia *et al.,* 2019). This is despite the low investment requirements in raising black soldier fly larvae (Abro *et al.,* 2022). Currently, the inclusion of BSF larvae in pig diets is acceptable in Uganda, hence production will meet a ready market (Chia *et al.,* 2020b). In addition, scaling up the rearing of BSF is likely to be embraced by the government of Uganda, as the enterprise could be a source of employment to many nationals. In their work, Abro *et al.* (2022) reported that using BSF larvae in animal diets could create between 1,252 and 563,203 new jobs annually in Uganda and lift over 4 million people from poverty in the next two decades. This implies that BSF larvae, if embraced as an ingredient to replace fish or soybean meals, could significantly contribute to improving the economy well-being of many Ugandans.

However, production statistics remain scanty, probably because the insect has not yet gained popularity, particularly in the pig sub-sector. On the other hand, BSF larvae purely grow on organic wastes, like animal manure and food wastes. Considering food wastes, for example, an average

income earner in Kampala produces about 0.4 kg of wastes per day (UNEP, 2021). According to Ibadurrohman *et al*. (2020), 800g of BSF larvae can be produced from 4 kg of waste. As of 2020, the population of Kampala city was 1,680,600 people (UBOS, 2020a), resulting into 672,240 kg of food wastes and about 134,448 kg of BSF larvae per day. At 14% level of inclusion in pig diets (Chia *et al.,* 2021), about 960,343 kg of complete feed could be prepared from BSF larvae raised on the food wastes from Kampala on a daily basis. Assuming 2 % losses during feed preparation (EW Nutrition, 2023), about 941,136.14 kg of complete feed can be prepared on a daily basis and 282,340,842 kg generated per year, assuming a 300-days feed preparation operation annually.

The urban population statistics for 2022 showed that there were over 12 million people in the urban centres of Uganda (Macrotrends, 2024). In this review, we estimated an average of 0.3 kg per day of food waste to be produced by an urban dweller. With such level of waste generation, urban dwellers are able to generate about 3,600,000 kg of food wastes per day equating to 720,000 kg of BSF larvae per day. At 14% level of inclusion of BSF larvae in complete pig diets, food wastes from urban dwellers can produce 5,142,857 kg of complete feeds per day. At 2% level of losses during preparation, food wastes from urban centres can produce 5,039,999.86 kg of complete feed on a daily basis and 1.51 million tons of complete feed a year, assuming a 300-days operation. According to Straub and Vernooij (2021), 1.5 million tons of complete feeds are needed to support intensive pig production systems a year. However, this figure is low, probably because they only considered the number of pigs which are actually currently reared intensively. For our case, however, we have assumed that all pigs in Uganda are reared intensively.

To estimate the possibility of Uganda to produce enough BSF larvae for her pigs, the following assumption have been laid: A daily feeding regime of averagely 2 kg per pig- not considering the physiological condition of the pig (whether piglet, sow, or boar) whose requirements may vary. All pigs are intensively managed and feeding is from the feeds containing BSF larvae as the protein source with no supplementation, as would otherwise be the case for semi-intensive management or free-range systems. If this be the case, annual food wastes from urban centres alone can produce enough BSF larvae for preparing feeds that can feed the 4.4 million pigs (UBOS, 2020b) of Uganda for approximately over 5 months.

Unfortunately, statistics on food wastes generated from rural areas is missing. In addition, information on wastes like animal manure, crop residues and other organic wastes is not well documented. However, a literal extrapolation from the statistics of urban centres could give a picture that Uganda can provided enough BSF larvae to sufficiently and sustainably supply proteins required in feeding pigs yearly, and even other enterprises like poultry and fish.

Potential challenges in the use of BSFL in pig diets

Although Uganda could potentially produce enough BSF larvae for use in pig diets, the use of BSFL in pig feed production is liable to a set of challenges. The most constraining factor reported is the inability to ensure a constant supply of organic wastes for raising BSF larvae. In addition, some people still perceive black soldier fly larvae as yucky (Adetunmbi, 2023), and this could deter uptake of their rearing. There is also a risk of accumulation of heavy metals in the BSF larvae, especially, if the substrate had a high heavy metal load (Adetunmbi, 2023; Shumo *et al.,* 2019). With poor sanitation there is also potential threat of pathogenic microbes occurring in the Black soldier fly larvae (Shumo *et al.,* 2019). Therefore, the source of substrate and hygiene in the rearing

room are crucial in preventing heavy metal and microbial accumulation. The animal feed industry should thus guard against these challenges.

Conclusion

Although there is limited evidence, our review of the available information, especially on the abundance of raw materials for growing BSF larvae reveals a potential of sustaining the use of BSF larvae as a protein source in pig diets. This implies that, if the use of BSF larvae in pig diets is embraced by all practitioners, the postulated pork demand can be met by local production. In the raising of BSF larvae, however, it is important to establish a reliable source of heavy metal-free substrates to avoid heavy metal accumulation in the larvae, which would end up in the food system. Furthermore, there is need to sensitize all stakeholders on the capability of using BSF larvae to sustain future pig production and its potential in ensuring food security as it will avert competition for soybean meal and fishmeal, thereby preserving them as ingredients in human diets. Studies need to be conducted on pig producers' perception of using BSF larvae in pig diets and on the consumer willingness-to-pay for pork from pigs raised on the diets.

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Assessing the Impact of Chickpea (*Cicer arietinum* L.), Prosopis Pods (*Prosopis juliflora*), and Soybean (*Glycine max*)-Based Diets on Bee Performance and Nutritional Value

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Abstract

The study evaluated the proximate composition of soybean (*Glycine max*), chickpea (*Cicer arietinum* L.), and Prosopis (*Prosopis juliflora*) pod meal-based bee diets. The three major ingredients were selected deliberately due to their availability and cost. Proximate analyses were conducted at Egerton University, Animal Nutrition laboratory. There were three experimental diets with three replicates each: T1 (soybean meal), T2 (chickpea), and T3 (ground Prosopis pods). Prosopis pods were harvested by plucking mature pods from the tree branches at the Kenya Agriculture and Livestock Research Organization (KALRO), ABIRI Centre (0°28'10.1"N, 35°58'59.79"E). They were dried and ground to pass through a 1mm screen. Proximate analyses were carried out following the AOAC guidelines. All variables were subjected to analysis of variance (ANOVA) in a completely randomized design (CRD) using the SAS 9.4 statistical package. The results indicated that there were significant differences at ($p < 0.05$) between the CP content of diets. Treatment (T1) (263.4 g/kg DM) and T2 (261.7 g/kg DM) had the highest CP, while T3 (250.6 g/kg DM) had the lowest compared to T1 and T2. Similar trends were observed in ash content, with T3 having the highest (39.1 g/kg DM), while T1 and T2 were not significantly different, with 36.5 g/kg DM and 34.4 g/kg DM, respectively. There were no significant differences ($p > 0.05$) in CF in all the treatments. There were significant differences in the fat content, with T1 having the highest, 73.4 g/kg DM, followed by T3 with 40.0 g/kg DM, while T2 had the lowest, with 31.2 g/kg DM. In the supplemental diets, T1, composed of 30% soybean, 45% sorghum flour, 10% skimmed milk, and 15% brewer's yeast, contained a significantly higher CP content compared to T2 and T3. This was in agreement with other studies that indicated that the inclusion of specific ingredients in a diet impacted CP levels in animal feed. From the chemical analyses, brewer's yeast had the highest crude protein content. Treatment T1, consisting of 30% soybean, 45% sorghum flour, 10% skimmed milk, and 15% brewer's yeast, had the highest fat content among the supplemental diets. The results of this study showed that a combination of soybean, sorghum, skimmed milk, and brewer's yeast mixed with honey was the best for bee feeding.

Key Words: Ash, Crude Protein, Dry matter, Honeybee, *Prosopis juliflora* pods

1.0 Introduction

Beekeeping contributes significantly to domestic income generation, environmental conservation via pollination services, apitherapy, and food and nutrition security on a global scale (Patel *et al*., 2021). The consistent growth of the apiculture enterprise over time can be attributed to the implementation of contemporary beekeeping technologies (Etxegarai-Legarreta & Sanchez-

Famoso, 2022). The beekeeping industry has encountered several obstacles, including the depletion of nectar and pollen resources, the destruction of their natural habitat by human activities, and the application of hazardous chemicals in crop cultivation (Dicks *et al*., 2021).

The availability of high-quality pollen and nectar, which are essential for bee survival and development, is severely limited during dearth periods. Another component that impacts bee populations and well-being is bee feed (Ahmad *et al*., 2021). A deficiency in bee forage may result in a decline in bee populations or the manifestation of indicators of nutritional stress. According to Abrol and Abrol (2012), the honey bee is a good example of how nutritional stress can result in a variety of issues. Nutritional stress shortens the life span of honey bees and makes them less-effective foragers (Ahmad *et al*., 2021). Honey bees fed on a high-quality diet experienced less stress when exposed to *Nosema apis*, *Nosema ceranae*, and Varroa destructor (Lamontagne-Drolet *et al.* 2019). Assessing the potential use of locally sourced feed resources in honeybee nutrition is, hence, of the utmost importance (Ahmad *et al*., 2021).

Supplements for bees often contain soybeans. Bee dietary supplements usually include a combination of actual pollen, soy flour or protein isolate, yeast (to increase protein and vitamin B complex), vitamin and mineral supplements, sugar, honey, or oil (for additional fat), and sometimes other ingredients (Widowati *et al*., 2020). A larger concentration of pollen indicates a higher quality supplement. Grinding roasted soybeans into a fine powder produces soy flour, a low-carbohydrate, high-protein food product (Widowati *et al*., 2020). Different processing methods result in soy flour with different proximate compositions. When there is a lack of pollen, chickpea flour may be the best alternative to consider. Ghramh and Khan (2023) found that chickpea flour is high in protein, carbohydrates, lipids, and moisture. It is necessary to evaluate the appropriateness of various flours with high protein and other critical constituents for bee diets, such as ground *Prosopis juliflora* pods.

The majority of bee research has relied on brewer's yeast in their formulations due to its high protein content, which is crucial for the bee colonies' activity, particularly during the dearth period (Paray *et al*., 2021). The hypopharyngeal gland also relies on it during its development. A worker bee's hypopharyngeal gland develops in correlation with the amount of protein consumed and the bee's age (Ghramh & Khan, 2023). Sorghum flour, when utilized as a supplemental feed, can be extremely beneficial to bee diets. According to Ghramh and Khan (2023), sorghum flour is an excellent source of carbohydrates, proteins, and a number of necessary minerals such as magnesium, calcium, and potassium. Bees can use the proteins it provides as a protein supplement. Unlike other species of animals, bees are not affected by tannins. When bees are actively foraging across long distances, they rely on the carbohydrates in Sorghum to keep them going (Wakgari & Yigezu, 2021).

Incorporating natural pollen and other high-protein foods into the recipe is crucial for satisfying the honeybees' nutritional needs, even though it cannot completely substitute the variety of nutrients present in pollen. This experiment was conducted to assess the nutritive value of chickpea (*Cicer arietinum* L.), Prosopis pods (*Prosopis juliflora*), and soybean (*Glycine max*)-based bee diets and their effects on larval development, maintenance of colony strength, and honey production. Chemical analyses determined the dry matter, ash, crude fibre, crude protein, and fat content of the diets using the AOAC (2006) standard procedures.

2.0 Material and Methods

2.1 Study Site

Field experiment was carried out from March to August 2023 at the Dryland Research Training and Ecotourism Centre (DRTEC), Chemeron Marigat, Baringo County, Kenya. It is an interdisciplinary research and coordination centre for Egerton University, which is 1080 m above sea level 0°28'10.1"N 35°58'59.79"E. It receives 700-950 mm rainfall per year with peaks in April and July/August, but is generally very erratic. The annual mean temperature is 23°C (Kemboi *et al.*, 2021). Feed ingredients were subjected to proximate analysis at Egerton University, Department of Animal Sciences Animal Nutrition laboratory. Egerton University is in Njoro sub-county, Nakuru County, 0°22'11.0 "S, 35°55'58.0 "E, 1,800m above sea level with an average temperature of between 17° C and 22° C. The annual rainfall is 1,200±100 mm (Darboe *et al*., 2023).

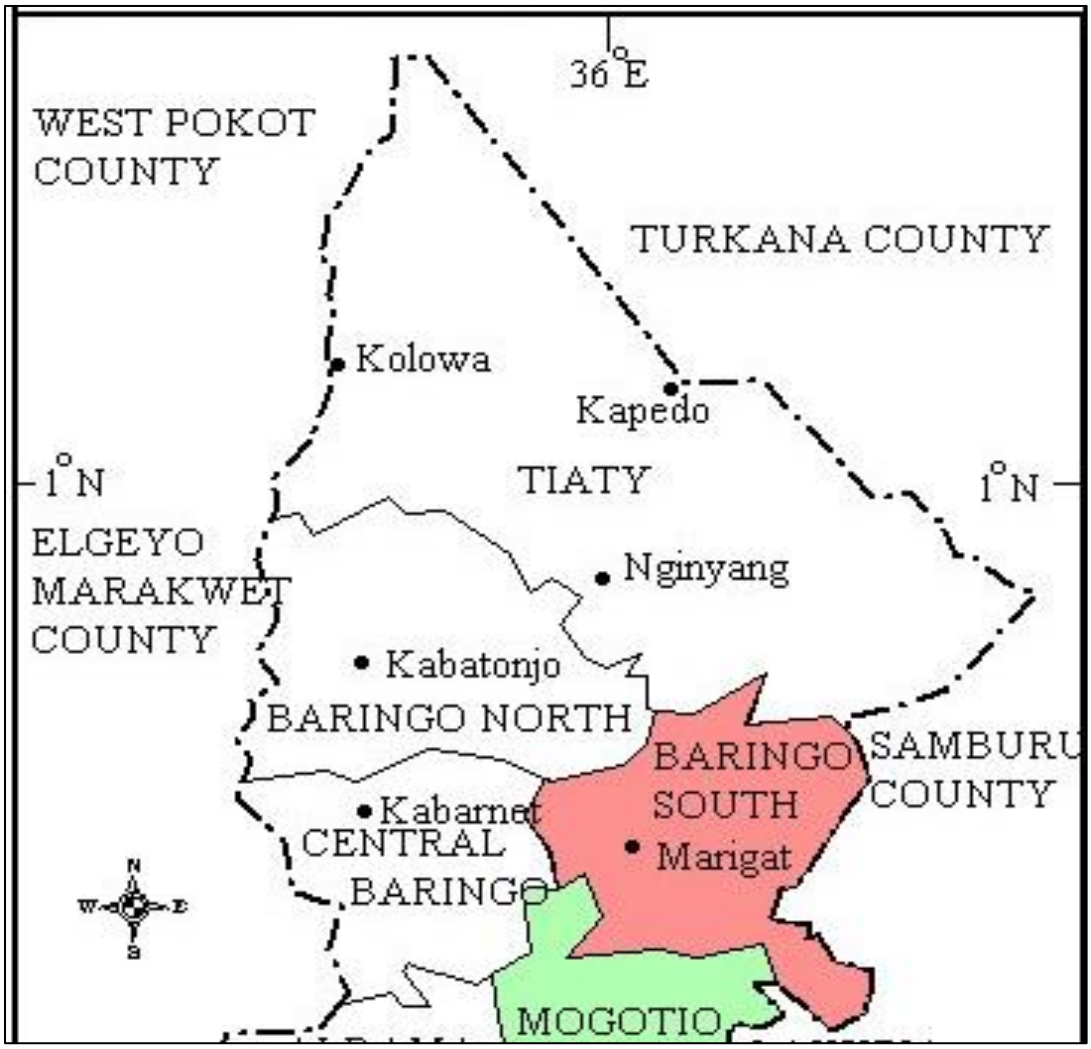

Figure 2. 1: Map showing the Study Site

Source: Survey of Kenya, 2022

2.2 Collection of *Prosopis juliflora* Pods and Preparation of Experimental Diets

Mature Prosopis pods were harvested by plucking from the branches at the Kenya Agriculture and Livestock Research Organisation (KALRO), ABIRI Centre. The Centre is located in Marigat Sub-County, Baringo County, Kenya (0°28'10.1"N, 35°58'59.79"E). The Centre is located in Marigat Sub-County, Baringo County, Kenya. It receives 700-950 mm of rainfall per year, with peaks in April and July/August, but is generally very erratic. The annual mean temperature is 23°C (Kemboi *et al*., 2021). They were sorted, dried and then ground to pass through a 1mm screen. After grinding, the pod flour was packaged in airtight glass jars to protect it from external contaminants, stored in a cool, dark, and dry place to avoid exposure to sunlight and heat, which can intensify nutrient degradation. This storage was meant to ensure preservation of nutrients, extend shelf life and to avoid spoilage.

2.3 Preparation of experimental diets

There were three experimental diets with three replicates each: T1= 30% soybean+45% sorghum flour+10% skimmed milk + 15% brewer's yeast T2= 30% chickpea+25% sorghum flour+ 5% skimmed milk + 40% brewer's yeast T3= 20% Prosopis pod flour +30% sorghum flour+ 5% skimmed milk + 45% brewer's yeast (Table 2.1). This study relied on guidelines and best practices developed by experts in the honeybee nutrition field.

Table 2. 1: Proportion of Different Ingredients in the Diets

Component	T1 (30% Soybean)	T2 (30% Chickpea)	T3 (20% Prosopis pod flour)
Soybean (%)	30	0	0
Chickpea (%)	0	30	0
Prosopis pod flour (%)	0	0	20
Sorghum flour (%)	45	25	30
Skimmed milk (%)	10	5	5
Brewer's yeast (%)	15	40	45
Total (%)	100	100	100

2.4 Proximate Analysis

Dry matter (DM) was determined by drying in a hot air oven at 105°C for 24 h following standard method 925.09 (AOAC, 2006), Ash by burning the samples in a muffle furnace at 550°C for eight hours following standard method 923.03 (AOAC, 2006), ether extract by the Soxhlet method (using ether) following standard methods 920.39 (AOAC, 2006). Total nitrogen for crude protein (N x 6.25) determination was obtained using the micro-Kjeldahl method following standard methods 920.87 (AOAC, 2006).

2.5 Statistical Analysis

The statistical model used was:

$$Yij = \mu + \tau i + \varepsilon ij$$

Where: Yij was the random variable representing the response to the treatment I observed. μ was the overall mean; τi was the (additive) effect of the i^{th} treatment, (i = 1, 2, 3, 4); εij was the random error for the i^{th} treatment.

2.6 Data Analysis

All variables were subjected to analysis of variance (ANOVA) in a completely randomized Design (CRD) utilizing the SAS 9.4 (SAS, 2009). Means were separated using the Duncan Multiple Range Test (DMRT) procedure at a 0.05 Significance level (SAS, 2009).

2.7 Results

The proximate analysis of the ingredients differed significantly ($p<0.05$), as shown in Table 2.2. Brewer's yeast recorded the highest DM with 950.0 gKg^{-1} DM, followed by Soybean flour with 948.7 gKg^{-1} DM, while Chickpea flour recorded the lowest with 913.6 gKg^{-1} DM. Soybean flour contained the highest with 437.0 gKg^{-1} DM, followed closely by Brewer's yeast with 420.8 gKg^{-1} DM. Chickpea flour had 208.6 gKg^{-1} DM, while Prosopis pods had 151.1 gKg^{-1} DM, and the lowest was Sorghum flour with 98.4 gKg^{-1} DM. Brewer's yeast had the highest ash content with 66.8 gKg^{-1} DM, with the lowest being Sorghum flour with 16.5 gKg^{-1} DM. Soybeans had the highest crude fiber with (147.3 gKg^{-1} DM). At the same time, Brewer's yeast recorded the lowest with 19.2 gKg^{-1} DM. The fat content varied significantly, with Soybean flour having the highest with 188.3 gKg^{-1} DM, while ground Prosopis pods had the lowest with 18.7 gKg^{-1} DM.

Table 2.2: Proximate Composition of the ingredients (gKg^{-1} DM)

Ingredient	DM	Ash	CP	CF	Fats
Soybean flour	948.7	45.8	437.0	147.3	188.3
Chickpea flour	913.6	26.0	208.6	142.6	45.1
Prosopis juliflora	943.6	59.0	151.1	138.9	18.7
Brewer's yeast	950.0	66.8	420.8	19.2	36.5
Sorghum flour	921.6	16.5	98.4	39.3	28.2

DM=Dry matter, CP=Crude protein, CF=Crude Fiber

Results from the proximate analysis displayed varying trends across the treatments, as tabulated in Table 2.3. There was a significant difference ($p<0.05$) between the CP of diet T3 (250.6 gKg^{-1} DM), while T1 and T2 had no significant difference. (263.4 gKg^{-1} DM and 261.7 gKg^{-1} DM) respectively. Similar trends were observed in Ash content, with T3 recording the highest (39.1 gKg^{-1} DM), while T1 and T2 had no significance and recorded 36.5 gKg^{-1} DM and 34.4 gKg^{-1} DM, respectively. There were no significant differences ($p>0.05$) in CF across all the treatments in this study. However, significant differences were witnessed in the fat content at ($p<0.05$), with T1 recording the highest with 73.4 gKg^{-1} DM, followed by T3 with 40.0 gKg^{-1} DM, while T2 had the least with 31.2 gKg^{-1} DM.

Table 2. 3: Chemical Composition of the Supplemental Diets (gKg^{-1} DM)

Treatment	CP	Ash	CF	Fats
T1	263.4±0.38[a]	36.5±0.05[b]	73.5±0.21[a]	73.4±0.12[a]
T2	261.7±0.12[b]	34.4±0.11[b]	76.5±0.07[a]	31.2±0.07[c]
T3	250.6±0.55[a]	39.1±0.04[a]	72.7±0.05[a]	40.0±0.06[b]
p-value	0.0272	0.0066	0.03036	<0.0001

[a, b , c,] means in the same column with different superscripts are significantly different at p<0.05 T1= 30% soybean+45% sorghum flour+10% skimmed milk + 15% brewer's yeast T2= 30%chickpea+25% sorghum flour+ 5% skimmed milk + 40% brewer's yeast T3= 20%ground Prosopis pods+30% sorghum flour+ 5% skimmed milk + 45% brewer's yeast.

2.8 Discussion

The proximate composition of ingredients in this study showed significant variations in vital nutritional components, crude protein (CP), crude fiber (CF), Ash, and fats. Brewer's yeast had the highest CP content, similar to studies by Terefe *et al*. (2023). Soybean flour also contained a high CP, concurring with the findings by Pope *et al*. (2023). Brewer's yeast is a valuable ingredient for bee diets; it is rich in protein, which is critical for the growth and development of honeybees, especially for larvae and young bees. Similarly, soybean flour contains high levels of protein essential for the production of bee brood (eggs, larvae, and pupae) and for the overall health of the bee. While bees do not digest fiber, amount not exceeding 7% in their diet can be beneficial for gut health and overall colony function. Ash content represents the mineral content of the ingredients, which are essential for various physiological functions in honeybees, including enzyme activation, nerve function, and overall health.

A diverse range of minerals in the diet contributes to the overall well-being of the bee colony (Pudasaini *et al*., 2020). The presence of fats in the diet is essential for bees, especially during times when they need energy reserves, and is also necessary for the production of beeswax and other physiological processes (Esanu *et al*., 2018). The specific types of fats and their ratios in the diet can influence the overall health and productivity of the bee colony. Diet T1, which included 30% Soybean, 45% Sorghum flour, 10% Skimmed milk, and 15% Brewer's yeast, showed a considerably higher crude protein (CP) content compared to treatments T2 and T3 in the supplemental diets. The finding is consistent with a previous study by Jach *et al.* (2022) that suggests the presence of specific ingredients can influence the amounts of CP in animal diets.

Ash content was most significant in T3, which had a more considerable amount of Brewer's yeast. This implies a possible correlation between the concentration of yeast and the mineral content, a phenomenon previously investigated by Delphine *et al*. (2023). Brewer's yeast's high mineral content may be the cause of T3's greater ash level. Brewer's yeast was found to have a significant impact on ash content; adjusting its concentration in formulations to achieve desired mineral levels

in the final product is crucial. There was considerable variance in the fat content of the diets, with T1 having the most significant quantities.
This aligns with the findings of Ricigliano *et al*. (2022), who emphasized the impact of ingredient ratios on the lipid composition of animal meals. The increased fat level in T1 can be due to the incorporation of Soybean and Brewer's yeast, both of which are recognized for their comparatively elevated fat content. This implies that bees consuming this diet T1 had access to more energy. They require this energy for various activities such as foraging, hive maintenance, and temperature regulation. The increased fat content may contribute to meeting these energy demands. These findings highlight the significance of carefully choosing ingredients and determining the appropriate ratios when developing bee diets to fulfill specific nutritional needs. Subsequent investigations could prioritize the determination of amino acids and minerals to augment the nutritional composition of bee feed, hence enhancing honeybee performance and health.

2.9 Conclusion and Recommendation

This study found that Brewer's yeast and soybean flour are notably good supplements in the bee diet due to their high protein content. Additionally, combining different protein sources in the diet can help ensure a more complete amino acid profile. Overly, T1= 30% soybean+45% sorghum flour+10% skimmed milk + 15% brewer's yeast was the best ranked diet. This study recommends making use of high-protein sources, such as Brewer's yeast and Soybean flour combined with sorghum and skimmed milk to come up with high quality pollen supplement for honeybees.

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Knowledge Roles in Agricultural Information Networks: Evidence from Dairy Information Networks in Nakuru County, Kenya

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Abstract

With social networks increasingly becoming important in the determination of critical social and economic outcomes, this paper interrogates knowledge roles in dairy information networks in Nakuru County, Kenya. Multi-stage sampling is used to select 390 dairy farmers operating in formal and informal dairy networks. Multinomial logit regression is used to evaluate the determinants of knowledge roles for smallholder farmers. Farmers' gender, access to extension services, and group leadership increase the likelihood of a dairy farmer being a knowledge sharer, rather than a seeker, of dairy information. With men dairy farmers being likely knowledge seekers and women dairy farmers being likely knowledge sharers, there is need for dairy trainings to be geared towards attendance by men dairy farmers. Men dairy farmers are likely knowledge brokers relative to women dairy farmers, implying higher incomes accruing to men dairy farmers. Group leaders are likely knowledge sharers, implying the extant dairy information network structure predisposes them towards better knowledge diffusion opportunities. Better educated dairy farmers are likely knowledge seekers, implying high opportunity costs for them in the procurement of dairy information. Knowledge diffusion policies should thus be geared towards the less educated dairy farmers.

Key words: Dairy information networks , Knowledge seeker, Knowledge sharer, Knowledge broker , Multinomial logistic regression.

Introduction

One of the most potent ideas in the social sciences is the notion that individuals are embedded in the web of social relations and interactions (Borgatti, 2009). According to Qiao *et al*.(2019), knowledge diffusion is increasingly being recognized as a major driver of innovation, the foundation of firms' competitive advantage, and the key anchor of growth in firms. Reviewed literature (Qiao *et al*., 2019; Havhakor, 2018; Kane & Alvin, 2007) suggests knowledge gaps existing in the understanding of the emergent, highly intricate network-level dynamics. The literature further suggests that future research consider unpacking how knowledge spreads across networks. The justification for this lies in the fact that there currently is no directly deducible connection between emergent global patterns of knowledge diffusion and individual-level behavior.

Qiao *et al*. (2019) attempt to redress this through the interrogation of the nexus between specific network attributes and knowledge diffusion. Specifically, Qiao *et al*. discuss the distribution of distinct knowledge roles and the design of selection rules. The knowledge roles outlined are knowledge seekers and knowledge sharers. The percentage of knowledge seekers and knowledge

sharers has a negative and significant correlation with the extent of knowledge diffusion. This has the key implication that the extent of knowledge diffusion decreases in instances where knowledge brokers are replaced either by knowledge seekers or knowledge sharers. Qiao *et al*. additionally found that replacing knowledge brokers with knowledge seekers has less effect than if the same knowledge brokers are replaced by knowledge sharers.

This paper contributes to the growing body of literature on knowledge diffusion by identifying the factors that determine the likelihood of dairy farmers playing varied knowledge diffusion roles in agricultural information networks in Nakuru County, Kenya. A multinomial regression model is employed to disaggregate the factors that determine the likelihood of dairy farmers occupying three distinct knowledge diffusion roles: broker, seeker, and sharer. The next section gives a background of dairy production in Kenya, while section 3 presents the data and description of variables. Section 4 describes the multinomial regression model, whereas section 5 presents the empirical results. Section 6 provides the study conclusion and policy implications arising therefrom.

Background of Dairy Production in Kenya

Globally, between 65% and 79% of farms are classified as smallholder (Lowder, 2016; Rapsomanikis, 2015). The livestock sector is broad and covers diverse agro-ecological, social, and political dimensions across continents, regions, and countries (Kingori, 2022). Milk production employs approximately 1.3 billion people worldwide, with smallholder dairy farmers accounting for more than 150 million farms (Chawala *et al*., 2019). The Kenya dairy industry contributes between 4% and 8% of the country's Gross Domestic Product (Bonilla *et al*., 2018; Kenya Dairy Board [KDB], 2016). About 80% of total milk output is produced by smallholder dairy farmers (Mawa *et al*., 2014 About 80% of total milk output is produced by smallholder dairy farmers (Mawa *et al*., 2014). About 1.2 million Kenyans are directly engaged in dairy production. In addition to contributing to economic growth, the dairy industry is identified as a significant enabler of household food security and income. It provides livelihoods to 25% of Kenyan households (GoK, 2019).

As a high-value enterprise, dairy farming in Kenya is recognized by the Nakuru County government as presenting profitable opportunities to increase demand for milk and dairy products through sustainable intensification and commercialization of smallholders and medium-scale producers (DFEP, 2018; DFEP, 2013). some of the challenges faced by smallholder dairy farmers in Kenya include; low economies of scale, low productivity, seasonal fluctuations, low dairy intensification, high costs of production, instability in milk supply, poor milk quality and safety, and the risk of unfair competition from oligopolies in milk processing (Odero-Waitituh, 2017; Bebe *et al*., 2016; Rademaker, 2016; Kibiego *et al*., 2015). Dairy productivity in Kenya is still significantly lower than the 6,000kg/cow/year potential yield of exotic dairy breeds (Kebebe *et al*., 2017; Njarui *et al*., 2016; Muasya *et al*., 2014; Njubi *et al*., 2009). We therefore seek to contribute to the existing body of knowledge by interrogating the knowledge diffusion roles played by dairy farmers in agricultural information network.

3.

3.1 Multinomial regression model

This study employs a multinomial logit regression model to evaluate the determinants of knowledge roles in dairy information networks. We employ the generic model as conceptualized by Greene (2020).

Let $\pi(x) = p(Y = 1|X = x) = 1 - p(Y = 0|X = x)$

The binary logistic regression model becomes;

$$Logit\ [\pi(x)] = log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \beta x$$

With the odds expressed as

$$\left(\frac{\pi(x)}{1-\pi(x)}\right)$$

The binary model is thus expressed as;

$$Logit\ [\pi(x)] = log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \log[\exp(\alpha + \beta x)] = \alpha + \beta x \quad (1)$$

Equation (1) may be extended to models with multiple explanatory variables.

Let k denote the number of predictors for a binary response, Y by $x_1, x_2,\ldots, x_k$. The model of the log odds thus becomes;

$$logit[P(Y = 1)] = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k \quad (2)$$

The alternative formula, specifying $\pi(x)$ is expressed as;

$$\pi(x) = \frac{\exp(\alpha + \beta x)}{1 + \exp(\alpha + \beta x)} \quad (3)$$

To construct the logits in the multinomial case, one of the categories is treated as the base level, and all the logits are constructed relative to it. We assume n independent observations with p explanatory variables, with the qualitative response variable having k categories.

,

Let π_j denote the multinomial likelihood of an observation falling in the j^{th} category. To find the relationship between this probability and the p explanatory variables $x_1, x_2,\ldots, x_p$, the multinomial regression model is expressed thus;

$$log\left[\frac{\pi_j(x_i)}{\pi_k(x_i)}\right] = \alpha_{01} + \beta_{1j}x_{1i} + \beta_{2j}x_{2i} + \cdots + \beta_{pj}x_{pi} \quad (4)$$

where $j = 1,2,\ldots,(k-1);\ i = 1,2,\ldots,n$

Since all π_s add to unity, equation (4) is further reduced to;

$$log\left(\pi_j(x_i)\right) = \frac{\exp\left(\alpha_{01} + \beta_{1j}x_{1i} + \beta_{2j}x_{2i} + \cdots + \beta_{pj}x_{pi}\right)}{1 + \exp\left(\alpha_{01} + \beta_{1j}x_{1i} + \beta_{2j}x_{2i} + \cdots + \beta_{pj}x_{pi}\right)} \quad (5)$$

For $j = 1,2,\ldots,(k-1)$, the model parameters are estimated by the method of maximum likelihood.

As earlier stated, for the multinomial linear regression model, the estimate for the parameter can be identified compared to a baseline category. Let $\pi_j(\mathbf{x}) = p(Y = j|\mathbf{x})$ at a fixed setting $\mathbf{x}$ for explanatory variables. With $\sum_j \pi_j(\mathbf{x}) = 1$ for observations of that setting. We treat the counts at J categories of Y as multinomial with probabilities $\{\pi_1(\mathbf{x}),\ldots,\pi_j(\mathbf{x})\}$; the baseline category is thus expressed as;

$$log\frac{\pi_j(\mathbf{x})}{\pi_k(\mathbf{x})} = \alpha_j + \beta_j'\mathbf{x} \quad (6)$$

where $j = 1, \ldots, (J-1)$;$k = 1, \ldots, (K-1)$ simultaneously describe the effects of $\mathbf{x}$ on these $(J-1)$ logits.

4. Data, and Description of Variables

4.1 Study Area

The study was conducted in Nakuru County in Kenya. Nakuru County is located in the middle of the Rift Valley region of Kenya (GoK, 2015). Nakuru County lies between latitude $0° 10' \; and \; 0° 20'$ South and longitude $36° 0' \; and \; 36° 10'$ East. Administratively, Nakuru County is further divided into the following sub-counties: Gilgil, Kuresoi North, Kuresoi South, Molo, Naivasha, Nakuru East, Nakuru West, and Nakuru North, and Njoro (GoK, 2018). The county receives between 700 mm and 1,200 mm of rainfall annually, with an average annual rainfall of approximately 800mm. Nakuru has two rainy seasons: April, May and August (long rains) and October and December (short rains).

4.2 Sampling scheme

Our data is derived from a survey of 390 households in four of the six sub-counties in Nakuru County. Table 1 shows the sample distribution per Sub-County. The sampling ratios are derived from the Kenya Housing and Population Census data of 2019.

Table 13: Sampling distribution per Subcounty

Sub-county	Population	Sample size	Sample ratio
Gilgil	185,209	97	24.87%
Rongai	199,906	96	24.62%
Molo	156,732	85	21.79%
Njoro	238,773	112	28.72%
		$n = 390$	100.00%

Source: KNHPC Report Vol.II (2020)

the study employs a multi-stage sampling procedure. Firstly, Nakuru County was purposively selected due to its dairy farming potential, as indicated by current reviewed literature on dairy production, and as seen by the significant number of smallholder dairy farmers (MoALFI, 2019; MoALFI, 2013). Secondly, four sub-counties-Njoro, Molo, Rongai and Gilgil- were purposively selected to represent high and medium potential agro-climatic zones in Nakuru County. Two wards per Sub County selected were then chosen purposively. Finally, snowball sampling is used to select smallholder dairy farmers to be interviewed. The interviews were administered by use of semi-structured questionnaires. In line with COVID-19 protocols, the questionnaire was administered by use of digital equipment such as smart phones and tablets. *KoboKollekt* software was employed as a digital research instrument for the study.

5.2 Multinomial Logistic Regression Results for Composite, Formal and Informal Networks

Tables 3 presents the multinomial logistic regression results for formal, informal and for the composite network. As outlined in the conceptual framework, three knowledge roles were contemplated for the dairy farmer: knowledge seeker, knowledge sharer, and knowledge broker.

In modelling the same, knowledge seeker was picked as the base case. The coefficients and the relative risk ratios (RRRs) thus generated are interpreted with respect to the base case aforementioned. Women dairy farmers are more likely to be knowledge sharers relative to being knowledge seekers to men dairy farmers at the 1% level of significance. The relative risk ratio of 0.4571 implies that men dairy farmers are less likely to be knowledge sharers relative to being knowledge seekers. Moreover, though not statistically significant, results show that men farmers are more likely to be knowledge brokers within the formal and informal networks. Indeed, the RRR suggests they are almost twice as likely (1.895) to be brokers than knowledge seekers.

Regarding dairy farmers' number of informational links, with RRR of 1.0669, knowledge sharers are equally as likely to have the same amount, or number of informational links-as indicated by their respective edge weights-as knowledge seekers at the 5% level of significance. Additionally, at the same level of significance (5%), knowledge sharers are less likely to access extension services compared to knowledge seekers. Farmers accessing extension services are 0.5738 times less likely to be knowledge sharers than knowledge seekers.

At the 5% level of significance, dairy farmers who identify as group leaders are almost twice as likely (1.8954) to be knowledge sharers than knowledge seekers in both formal and informal networks. Though not significant, group leaders are 2.39 times more likely to be knowledge brokers relative to being knowledge seekers. Regarding the highest level of education attained by a dairy farmer, results show that farmers with comparatively higher levels of education are less likely to be knowledge brokers or seekers. These results are however not significant.

Regarding formal dairy networks in Nakuru County, farmers' age and farmer group leadership returned significant results in the comparison of knowledge brokers and knowledge seekers. Farmers' gender, access to extension services, farmer having relatives in group leadership and farmer group leadership returned significant results in comparison of knowledge sharers and knowledge seekers. Older farmers were 0.891 times less likely to be knowledge brokers relative to them being knowledge seekers. A typical dairy farmer occupying a leadership position in a group makes them less likely to be knowledge brokers relative to them being knowledge seekers. Comparing knowledge sharers with the base case, men farmers are less likely to be knowledge sharers, and are more likely to be knowledge seekers at the 1% level of significance. At the same level of significance, results show that access to extension services predisposes dairy farmers to be 0.3243 times less likely to be knowledge shares relative to the said farmers be knowledge seekers. Having kin in group leadership position had the largest marginal effect, with results showing that such dairy farmers were 27.8 times more likely to be knowledge sharers, and less likely to be knowledge seekers.

For formal networks, and at the 1% level of significance, only farmers' level of education returned significant results in the comparison of knowledge brokers and knowledge seekers. A comparatively higher level of educational attainment predisposes dairy farmers to be less likely to be knowledge brokers relative to being knowledge seekers. Though not significant, results for farmers' gender, educational attainment, node weights, edge weights, extension access, kin in group leadership, and farmer in group leadership mirror those for formal and all networks.

Table 3: Multinomial regression results for composite, formal and informal dairy information networks in Nakuru County, Kenya

	Composite network				Formal network				Informal network			
Base case: Knowledge seeker	Knowledge Broker		Knowledge sharer		Knowledge Broker		Knowledge sharer		Knowledge Broker		Knowledge sharer	
	beta	RRR[3]	beta	RRR	beta	RRR	beta	RRR	beta	RRR	beta	RRR
Age (years)	-0.031	0.969	0.015	1.015	-0.116**	0.891	-0.005	0.995	0.022	1.022	0.027	1.027
Gender (*1=male*)	0.64	1.9	-0.783***	0.457	0.931	2.536	-1.331***	0.264	0.314	1.369	-0.42	0.657
education level	-0.587	0.556	-0.012	0.988	-0.083	0.921	-0.040	0.961	-0.808***	0.446	-0.082	0.921
node weight	0.104	0.901	0.027	1.027	0.792	2.208	0.036	1.036	-0.561	0.571	0.203	1.225
edge weight	0.09	1.094	0.065**	1.067	-0.158	0.854	0.049	1.05	0.235	1.265	0.038	1.039
extension access	-0.048	0.953	-0.556**	0.574	-0.462	0.629	-1.126***	0.324	-0.267	0.765	-0.132	0.877
kin in group leadership (*1=yes*)	0.077	1.079	0.228	1.256	1.364	3.911	17.141***	27.8	0.106	1.112	0.052	1.053
group leadership (*1=yes*)	0.871	2.39	0.639**	1.895	-13.085***	0	0.966**	2.63	1.023	0.006	0.264	1.303
Intercept	-2.73	0.065	-0.746	0.474	1.353	0.0652	1.5839	4.874	-5.182**	0.065	-1.90*	0.149

[3] Relative Risk Ratio

6. Conclusions and Implications

6.1 Conclusions

With the role of interpersonal networks in facilitating knowledge diffusion having been demonstrated in a number of studies, this paper contributes to the growing body of literature on by identifying factors that determine likelihoods of dairy farmers playing varied knowledge diffusion roles in agricultural information networks in Nakuru County, Kenya. A multinomial regression model is employed to disaggregate factors determining the likelihood of dairy farmers occupying three knowledge diffusion roles. The knowledge seeking role is employed as the base case in the multinomial regression model.

Women dairy farmers are more likely to be knowledge sharers than knowledge seekers, whereas men farmers are likely to be knowledge seekers than knowledge sharers. With respect to knowledge brokerage, men farmers are twice as likely to be knowledge brokers relative to women farmers. Farmers accessing extension services are more likely to be knowledge seekers than knowledge sharers. Dairy farmers who double as group leaders are twice as likely to be knowledge sharers as knowledge seekers in both formal and informal networks.

Though not significant, group leaders are more likely to be knowledge brokers than knowledge seekers. Farmers with comparatively higher levels of education are less likely to be knowledge brokers or seekers. For formal dairy information networks, older dairy farmers are more likely to be knowledge seekers than knowledge brokers. A dairy farmer occupying a leadership position is more likely to be a knowledge seeker than a knowledge broker. A comparatively higher level of educational attainment predisposes dairy farmers to be more likely to be knowledge seekers than knowledge brokers.

6.2 Policy implications

Results showing likelihood of women dairy farmers being knowledge sharers than knowledge seekers may point to the fact that women dairy farmers have over time attended and been successfully trained on current dairy best practices compared to their men counterparts. This may in turn suggest a need for men dairy farmers to be encouraged to attend dairy trainings as and when available. This point is further strengthened by the significant results showing men dairy farmers to more likely be knowledge seekers than knowledge sharers within the dairy information network. The significant gender differentials observed in the results also provides further scope for future research on knowledge diffusion roles. It may be that cultures embedded in these networks see dairy farming as a woman's responsibility, rather than a man's.

The significant results showing likelihood of men dairy farmers being twice as likely to be knowledge brokers than women farmers may point to an observed advantage for men dairy farmers over women dairy farmers. Men dairy farmers are in a better position to leverage on their dairy knowledge for some income. Results further suggest that farmers with access to extension services are likely to be knowledge seekers than knowledge sharers. This may point to a willingness of men dairy farmers to actively seek, and pay, for information on current best dairy practices within dairy information networks. Further, it may be argued that a latent demand exists for the provision of extension services within the dairy networks, and thus the state may consider encouraging both public and private extension providers to participate in dairy information networks.

Results showing group leaders as knowledge sharers may point to the fact that central farmers are more trusted with leadership positions in dairy farmer groups; this allowing them to leverage on their centrality to share information on current best dairy practices with other dairy farmers. Strategies that promote the sharing of dairy expertise between leaders of dairy groups

and group members are recommended from a policy standpoint. Additionally, group leaders and members should be considered for platforming by extension platforms that are already a part of dairy information networks. When compared to traditional extension approaches, social networking sites like Facebook, WhatsApp, Telegram, and others may offer inexpensive and quick means of exchanging information, especially in the context of the expanding knowledge economy space in less developed economies.

The fact that better educated farmers are more likely to be knowledge seekers than brokers may point to high opportunity costs existing in the procurement of dairy information in dairy information networks for such farmers. Better educated dairy farmers, *ceteris paribus*, prefer to dedicate more of their temporal resources towards non-dairy economic activities whereas less educated dairy farmers prefer to dedicate more of their temporal resources towards dairy economic activities. Additionally, less educated dairy farmers are better able to leverage their dairy knowledge to earn income through brokerage of the same compared to better educated dairy farmers.

For both composite and formal networks, older dairy farmers are likely to be knowledge seekers than brokers. It may thus be argued that younger dairy farmers are better able to leverage on dairy knowledge to earn income through knowledge brokerage compared to older dairy farmers. For formal networks, group leaders are likely to be knowledge seekers than brokers. This is indicative of possible high opportunity costs existing for group leaders, while simultaneously predisposing the same to existing dairy training opportunities. Lastly, for informal networks, only dairy farmers educational level returned significant results in the multinomial regression model, with the results mirroring the composite and formal networks earlier discussed.

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Determinants of utilization of banana value addition among small-scale agripreneurs in Kenya: A case of Kisii County

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Abstract

There is increased demand of banana fruit and its processed products among the rural and urban population. Value addition reduces postharvest losses and increases crop productivity as well as crop income. Even though, the government and non-governmental organizations have promoted banana value addition, its utilization is still low in Kisii county Kenya. There is a dearth of information on the determinants of utilization of banana value addition. Previous studies on determinants of crop value addition, have focused on tomatoes, mangoes, tubers and root crops, with little emphasis on banana fruit. This necessitated the study. Mult-stage sampling procedure was used to select 201 respondents. Data were collected using semi-structured questionnaires and analysed using descriptive, inferential statistics and a Cragg's Double Hurdle model. The results revealed that banana value adders were involved in flour milling (36%) slicing and drying (31%) cleaning sorting and grading (26%) and crisps making (7%). Compared to non-value adders, value adders were significantly younger, produced more quantities of bananas, travelled longer distances to the market, received more trainings and extension visits, practiced farming as their main occupation, owned smaller farm sizes and majority of them did not access credit The decision to utilize banana value addition was significantly influenced by the total quantity of banana produced, type of roads, primary occupation, number of trainings and extension contacts, distance to output market, group membership, and access to credit. The extent of value addition was influenced by extension contacts, type of roads, total quantity of banana produced, and marital status (being married). The study recommends that the socioeconomic and institution factors influencing both decision and extent of banana value addition should be considered when formulating and implementing policies geared words promoting banana value addition.

Key Words: Agri-preneurs, Banana, Double hurdle, Utilization, Value addition

INTRODUCTION

Bananas (*Musa spp.*) are among the major fruit crops of the global economy and are mostly cultivated in more than 130 tropical and sub-tropical countries Easwari & Maruthupandi, 2020; Lalitha *et al.,* 2022). They play a central role in providing food and nutrition security and feed for livestock (Rono *et al.*,2020). As food, bananas are rich in minerals such as potassium, magnesium, sodium, phosphorus, vitamins including vitamin C, B_2 and B_6, fibre and energy (Gemechu *et al.,* 2021; Lalitha *et al.,* 2022). They ae consumed when ripe, boiled, or in processed forms such as chips, dried fruit, bread, ice cream, smoothies, and juice among others (Al-Dairi *et al.,* 2023).

Globally bananas have remained the second fruit and eighth food crop in the world (Jalawadi *et al.,* 2021; Thangavelu *et al.,* 2021). Presently, India China, and Indonesia are the leading producers in the world (Gebre *et al.,* 2022). The global production increased by about 150% in

the last three decades as experienced from the year 1985 to 2019 (FAO, 2020). Further, this production is expected to rise as a result of an increase in population and change in food consumption patterns (Sugianti *et al.,* 2022). Africa produces 25% of the world's banana volume in an area of 4 million hectares farmed by about 90% of smallholder producers (Nkwain *et al.,* 2022). Cameroon, Kenya, Cote d'Ivoire, Tanzania, and Uganda are the major producers (Olumba & Onunka, 2020)

The crop has been ranked the fourth starch food crop after maize, rice, and wheat in developing countries (Keba & Yilma, 2022; Masud *et al.*, 2022). The sub-sector contributes to 17.8% of the aggregate value of fruits and vegetables and 34.5% of the total fruits in Kenya (Horticultural Crops Directorate (HCD, 2020). There are 390,000 farmers growing bananas, with 84% being smallholders owning less than 0.2 hectares (Karienye *et al*., 2021). According to HCD (2020), Meru, Taita Taveta, Murang'a, Kirinyaga, Embu, Tharaka Nithi, Kisii and Nyamira are the major producers of bananas in Kenya. In addition, in Kisii and Nyamira counties, green bananas are the most preferred types while dessert types are commonly grown in central and Eastern regions including Meru, Embu, and Kirinyaga (Omondi *et al.,* 2020). One million metric tons are produced from about 80,000 hectares of land translating to mean yields of 12.5 metric tons which is worth KES 40 to 45 billion (Karienye & Kamiri, 2020).

Despite the health and socio-economic benefits of bananas, the value chain is hindered by production and market related factors. Among them include: low crop productivity, lack of access to better paying markets, low prices, decreasing prices, poor postharvest management, and inadequate farm incomes (Kumar & Achudhan, 2021; Natukwatsa, 2021). Banana agripreneurs sell their raw bananas at a low market price due to lack of access to postharvest handling attributed to inadequate access to credit, transportation problems and lack of banana cooperatives. Banana productivity is continuously declining due to conventional methods of banana production and poor agronomic practices (Tarekegn *et al.*, 2020). There is primarily poor coordination of banana agripreneurs within the cooperatives which could link them to local markets (Zinabu *et al.,* 2019). Also, due to changes in informal and formal channels of processors and markets, agripreneurs have no ability to sell their produce in staple food markets profitably (Wahome *et al.,* 2021).

Banana fruit is climacteric, heavy and highly perishable in nature, therefore much of the produce get spoiled during excess supply because markets become flatted (Chabi *et al.,* 2018). This is exacerbated by lack of storage facilities, improper handling, transport, marketing and processing (Singh *et al.,* 2018; Subbaiah *et al.,* 2018). In such scenarios, prices of bananas become low and decreases inconsiderably giving middlemen a chance to dominate the market. Under such circumstances, it is important to process banana to storable products for instance banana powder, flour, chips, dried slices, jam, beverages, baby foods among others (Kikulwe *et al.,* 2020). However, agripreneurs have inadequate technical knowledge on how to handle highly perishable produce in the fruit industry (Muigai *et al.,* 2021).

As a result of these challenges, the Kenya Livestock and Research Organizations (KARLO) previously had issued improved banana varieties to farmers to improve productivity and boost the crop income (Mwangi & Kariuki, 2015). Furthermore, approaches including use of cold storage facilities, hexanal technologies and 1-methylcyclopropene were introduced at farm level to increase the shelf life of fruits by minimizing the losses (Al-Daire *et al.,* 2023; Kahwai *et al*., 2021). However, banana productivity is still on the decline estimated at 4.5-10 tons per hectare against the international levels of 40-50 tons per hectare (Muthee *et al.,* 2019). Moreover, post-harvest losses are still on alarming rate estimated at 30-40%.

Banana value addition could provide a solution to increase crop productivity, minimize post-harvest losses hence boost farm incomes (Natukwatsa, 2021; Kathuri *et al*., 2021). An extra value can be added to a product or a service. Value addition means adding an extra feature to an original product or transforming the original product to a different product. In this context banana fruit was added value through cleaning, washing and grading, or transforming its original fruit to other products such as flour, dried chips, or crips. Transforming bananas into other products are profitable business opportunities that enhances profit margins of agripreneurs (Donkor *et al.,* 2018). Banana is one of the crops that has been targeted by the Kenyan government in its developmental agenda to promote value addition to enhance sustainable agriculture and agro-industrialization because banana fruit provides raw materials for industries and creates employment opportunities for the youth in the rural populations. In addition, rural economy is characterised by poor infrastructure, high poverty levels and food insecurity (Obaga & Mwaura, 2018). Thus, integration of rural agripreneurs in value addition would spur rural socio-economic development through exploitation of rural agro-processing (Donkor *et al.,* 2018).

Despite the known importance of value addition in the rural economy, both governments and non-governmental organizations have put in place interventions to promote the use of banana value addition. In spite of these efforts, the level of utilization of these value addition activities is still low. This is because, banana agriprenuers are still producing and marketing their raw fruits in the market with little or no attempt to make flour, dried chips, or crips (Marimo *et al*., 2020). Additionally, the influence of socio-economic and institutional factors on decision to participate in value addition and extent of participation is still not clear in the empirical literature. As the studies emphasizing on agripreneurs' decision and extent of utilization of banana value addition are limited, therefore the objective of this paper is to assess the determinants of utilization of banana value addition among small-scale agripreneurs in Kisii county. Thus, it's on this background that the study sought to fill these knowledge gaps among small-scale banana agripreneurs in Kisii County. Knowledge and information obtained from this study will enable policy makers to design policies and interventions aimed at promoting micro and small-scale banana agri-enterprise through value addition leading to increased production and consumption of banana and its value-added products for improved farm income and livelihoods.

Literature review on determinants of crop value addition

Previous studies on determinants of crop value addition, have focused on Irish potatoes, sweet potatoes, cassava and mangoes with little emphasis on banana fruit. Moreover, most studies have focused on factors influencing decision to adopt value addition with little or no attention on factors influencing the extent of adoption. For example, Orinda *et al.* (2017) used Heckman Two stage model to determine the factors influencing sweet potato and mango value addition in Kenya. The study stated that the decision of farmers to take up value addition was influenced by household size, total quantity produced, credit access, land size of the respondents, distance to the market and group membership. While the extent of value addition was affected by the distance to the market, group membership, credit access and total quantity produced. Moreover, a study in Kenya by Musyoka *et al*. (2020) also used Heckman Two stage model to model the factors influencing decision and extent of adoption of mangoes. The study found that the factors which significantly influenced the decision of mango value addition included off-farm income, access to cold storage facilities, price of value-added products, group membership, extension contact, farmers' awareness, amount of credit, and hired labour. While training, farmers' awareness and access to cold storage facilities distance to market and livestock equivalence had a significant effect on the proportion of mangoes value added.

Okeke *et al.* (2023) used Double Hurdle to determine the decision to invest in cassava value addition and extent of investment in Nigeria. The study found that sex, marital status, age, and cooperative membership had a significant influence on investment decision While level of investment was significantly influenced by sex, marital status, level of education, age, membership of cooperatives, return, and credit received. Jacob *et al.* (2023) used binary probit regression to examine the factors influencing the decision of cassava value addition in Nigeria. The study reported that the decision to add value to cassava was significantly affected by farm size, group membership, gender, farming experience, access to credit and education level.

A study by Khoza *et al.* (2019) determined the factors that influenced agro-processing in South Africa. The findings of the study revealed that the decision to participate in agro-processing was positively and significantly influenced by education level, access to trainings on agro-processing, and land tenure while distance to the market and off farm income had a negative significant on decision to participate. On the other hand, household size, education level, farm size, access to training, grain and livestock producers, and age had a significant influence on level of processing. Osondu *et al.* (2023) used multiple regression to examine the factors influencing decision of cassava value added technologies in Nigeria. The study reported that age, education level, marital status, extension contact processing cost annual income, group membership access to credit and quantity of casava produced had a significant effect to value addition while the adoption process was constrained by the following, inadequate capital, lack of market, inadequate access to credit inadequate knowledge of technologies, high cost of equipment and scarcity of labour

Maku *et al.* (2022) documented that access to good road network has a significant influence on participation in value addition. This is because agripreneurs easily transport their produce and products to the market hence enhancing trade of agricultural commodities Access to credits increases the likelihood of participation in value addition since agripreneurs will be able to purchase the necessary value addition equipment and facilities. Agripreneurs who are organised in cooperative or group memberships have better access to markets as they have a high bargaining power. A study by Esheya (2023) reported that marital status increased the probability of farmers to add value to cassava. Extension contacts supply agripreneurs with information on banana production, technology adoption, marketing and management and reduces risks with new technologies. Agricultural trainings also offer agripreneurs with technical skills experience and knowledge on adoption of agricultural technologies.

value addition, they give mixed results. Only two studies investigated the factors influencing the decision to adopt banana value addition. For instance, Muigai *et al.* (2021) in Kenya reported that access to credit and group membership influenced the decision to add value to banana fruit. While extension services, cropping systems, and gender of farmers by Natukwatsa (2021) in Uganda had a significant effect on decision to participate in banana value addition. There is no empirical information on determinants of banana value addition in Kenya. This study was therefore aimed at providing more evidence on factors influencing decision of participation in banana value addition and extent of participation using Cragg's Double Hurdle model. This model controls sample selection bias compared to Heckman Two stage model. Our study provides new evidence on policy related variables. This study aimed at informing the stakeholders including the ministry of agriculture, research institutions, and the private sector organizations on developing appropriate policies on banana value addition The study will lead to minimized post-harvest losses, increased agripreneurs' incomes and food security therefore attaining the global political goals of the United Nations through the use of value addition. Further, information on value addition and any related field will be available through the

findings and recommendations of this study, to future researchers who may have an interest to carry out research on the same.

METHODOLOGY

Study area

This study was carried out in Kisii County. The county is among the major banana producing areas in Kenya. It is located within the Western region of Kenya. It is found at latitude 0° 30'and 10° 0'South and longitude 34° 38'and 37° 61' East. The county receives bimodal rainfall. Long rains are experienced from March to June while short rains are received from September to November. The maximum and minimum temperatures ranging from 21°C and 30°C and 15°C and 20°C respectively. Smallholder farmers in this region depend on agriculture which is mainly rainfed. Both dairy and crop farming does well in the area. The main crops grown in the area include: bananas, tea, coffee and sugarcane, maize, beans, sweet potatoes, cassava, among others. Figure 1 shows a map of the study area.

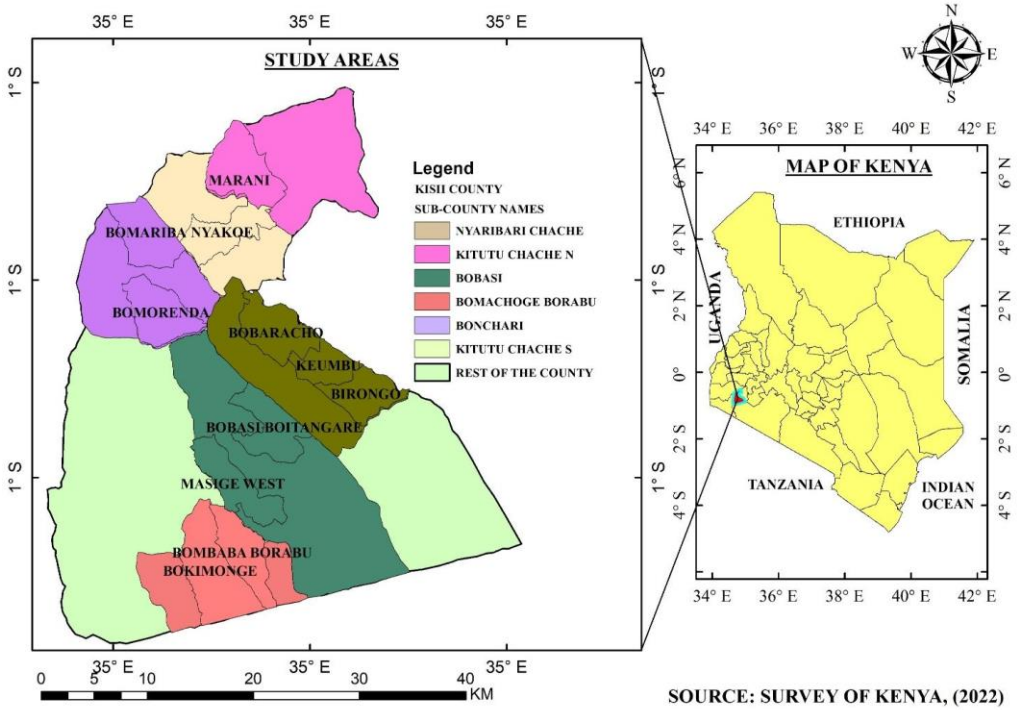

Figure 1: Location of the study area in Kisii County

Sample size determination

To determine the sample size of this study, the Cochran's (1977) formula was applied as follows:

$$n = \frac{Z^2pq}{e^2} \quad (1)$$

where: n = Sample size, p = is the proportion of small-scale banana agripreneurs that were engaged in value addition in the study area), (p=0.2), q = is the proportion in the target population estimated not to have characteristics being measured (q = (1-p) = 0.8), z = the standard value at a given confidence level (α = 0.05), e = the acceptable error (precision). The sample was determined as:

$$n = \frac{(1.96)^2(0.2)(0.8)}{(0.05)^2} = 246$$

The derived sample size for the study was 246. However, during the survey, the actual sample that was collected and used for analysis was 201 respondents because the response rate was 82%.

Sampling procedure

This study adopted a multi-stage sampling procedure to select the respondents. In the first stage, Kisii County was purposively selected. It comprised a region that was introduced early with banana value-addition whereby small-scale agripreneurs were oriented and incubated on the same. The second stage was the purposive selection of five Sub-counties with a high potential of banana production namely; Bonchari, Bobasi, Bomachoge Borabu, Kitutu Chache North, and Nyaribari Chache. Additionally, there have been several interventions introduced in these sub-counties geared towards promoting banana value addition. The third stage involved the purposive selection of ten wards whereby 61 banana value-adders and 140 non-value adders were selected using snowballing technique and simple random sampling respectively. The total respondents consisted of two hundred and one.

Data collection

Cross-section surveys were conducted in Kisii County which took place on 25th November and 10th December 2022. Primary data were collected through face-to-face interviews administered to the respondents by well-trained enumerators using semi-structured questionnaire. A pre-test of the questionnaire was done prior to actual data collection to test its reliability and validity. Secondary data were obtained by reviewing the past literature that was relevant for the study. Then the data which were collected, were coded and entered into SPSS (Version 25) and Stata (Version 17) software for analysis. Data was analysed by descriptive statistics such as mean, inferential statistics such as Chi square and t tests and Cragg Double Hurdle (DH) model

The categorical and continuous variables that were used in the econometric analysis are shown in Table 1. They were obtained from literature review of previous studies (Adam *et al.,* 2023; Bundi *et al.,* 2020; Khoza *et al.,* 2019; Korir *et al.,* 2020; Maku *et al.,* 2022; Mkandawire *et al.,* 2018; Muigai *et al.,* 2021; Musyoka *et al.,* 2020; Natukwatsa, 2021; Okeke et al, 2022Tijani, 2022). Before analysis, continuous variables were tested for multicollinearity problem using Variance Inflation Factor (VIF) (Table 2). The mean of VIF was 1.25 which was less than the recognized threshold value of 3 thus multicollinearity problem was not present. White test was also conducted to see the presence of heteroskedasticity. The test result indicated that the p-value was 0.1379 showing that there was no heteroskedasticity problems in the model (Table 3).

Empirical model specification

In this study, banana agripreneurs faced two hurdles in the participation of banana value addition. First hurdle was the decision to utilize banana value addition (1 Yes, 0 otherwise). The second hurdle was the extent of value addition measured as the quantity of banana fruit value added in kilograms. To determine the factors that influenced the decision of small-scale agripreneurs to participate in banana value addition and extent of participation, it was assumed that the two steps are independent. The binary probit model was used in the first stage to model the decision to participate and the truncated regression to model the extent of participation. Thus, Cragg's a double hurdle was applied following Alleluyanatha (2022). This study specified the Cragg's model as:

$d_i^* = Z_i\delta + \varepsilon_i \qquad \varepsilon_i \sim N(0, \sigma_\varepsilon^2)$ Decision to utilize (3)

Where: $d_i = 1$ if $d_i^* > 0$, and = 0 Otherwise

$y_i^* = X_i \beta + \mu_i \quad \mu_i \sim N(0, \sigma_\mu^2)$ Extent to utilize (4)

Where $y_i = 1$ if $y_i^* > 0$, and = 0 Otherwise

Whereby d_i^* is the latent variable showing agriprenuer's decision to utilize banana value addition and d_i is the observed value to utilize banana value addition = 1 if an agripreneur utilizes banana value addition and 0 if otherwise. y_i^* is the latent variable showing the extent of value-added banana and y_i is the observed responses on the quantity of banana value added. In addition, y_i= 0 for agripreneurs that did not utilize banana value addition and some positive values for agripreneurs that utilized banana value addition that is d_i = 1 if $y_i > 0$ and d_i = 0 if $y_i = 0$. δ and β are coefficients to be estimated. Z_i and X_i are the vector of factors that determined the decisions to utilize banana value addition and the quantity of bananas value-added respectively. ε_i and μ_i are the error terms that follows a normal distribution that is assumed to be independent (Cragg, 1971, Wooldridge, 2010).

The assumption holds that equation 3 and 4 are independent and the joint likelihood function of the Cragg model is shown below (Cragg, 1971; Tambo & Abdoulaye, 2013).

$$f(d, y/X, Z)\{1 - \Phi(X_i\beta)\}^{1(d=0)}\left[\Phi(X_i\beta)(2\pi) - {}_{2\sigma}^{1} - 1exp\left\{\frac{-(y-Z_i\delta)^2}{2\sigma^2}\right\}/\Phi\left(\frac{Z_i\delta}{\sigma}\right)\right]^{1}(d=1) \quad (5)$$

Where d is a binary variable = 1 if d is positive and 0 otherwise. Y is continuous variable for non-censored portion which is observed only when d = 1. The Cragg model indicates that if d > 0 and the value of y, given that y>0, may be influenced by δ and β. There is no restriction on X and Z showing that each decision can be explained by a different vector of independent variables according to Burke (2009). In addition, Tobit model is nested within Cragg's alternative for the reason that X = Z and $\beta = {}^{\delta}/_{\sigma}$. The Craggit model has been largely used in some studies which focused particularly on adoption of agricultural technologies and market participation (Gachuhi *et al.,* 2021; Khoza *et al.,* 2019; Kolapo *et al.,* 2020; Okeke e*t al*., 2022; Mohamed *et al.,* 2022).

Table1. Description of variables used in the first and second hurdles of the Cragg's Double hurdle model

Variables	Description	Unit	Expected sign	
Dependent			First hurdle	Second hurdle
Utilization decision	1 if agripreneur utilized, 0 otherwise	Dummy		
Extent of utilization	Kilograms of banana value-added	continuous		
Independent				
Age	Age of agripreneurs in years	Continuous	+/-	+
Gender	1 male 0 female	Dummy	+	+
Marial status	1 if married 0 Otherwise	Dummy	+	+
Education level	1non-formal 2 Primary level 3Secondary level 4Tertiary level	Categorical	+	+
Household size	Number of family members	continuous	_	_
Farmsize	Acres of total farm size	Continuous	+	+
Banana acres	Land acreage under bananas	continuous	+	+
Credit access	1 if accessed credit, 0 otherwise	Dummy	+/-	+/-
Extension	Number of extension Visits received annually	Continuous	+	+
Training	Number of trainings received annually	continuous	+	+
Group	Membership to cooperative or group 1 Yes, 0 Otherwise	Dummy	+	+
Quantity	Kilograms of bananas produced	Continuous	+	+
Experience	Years in banana arming	Continuous	_	+
Distance	Distance to output market in kilometres	Continuous	+	+
Occupation	Main Occupation 1 Farming 0 otherwise	Dummy	+	+
Type of road	Type of road accessed 1 tarmac 2 Murram 3 Earth	Categorical	+	+

Table 2. Variance inflation factor test results for continuous explanatory variable

Variable	VIF	1/VIF
Farm-Size in Acres	1.49	0.670004
Kilograms of banana harvested	1.46	0.686408
Number of trainings received by agripreneurs	1.30	0.7667753
Extension contacts received by agripreneurs	1.21	0.825155
Number of family members in households	1.06	0.945380
Age of agripreneurs head	1.05	0.950298
Distance from area of residence to nearest market	1.20	0.833053
Mean VIF	1.25	

Table 3. Heteroskedasticity test of explanatory variables using White test

Source	**Chi-square**	**df**	**p-value**
Heteroskedasticity	138.44	156	0.1379
Skewness	19.12	17	0.0003
Kurtosis	2.71	1	0.0044
Total	160.27	174	0.0036

RESULTS AND DISCUSSION

Descriptive statistics

Figure 2 shows the various banana value addition activities practiced by agripreneurs in the study area. Of the total sample, 61 banana agripreneurs were value adders and 140 were non-value adders. Value addition activities practised include: flour milling (36%) slicing and drying (31%), sorting and grading (26%) and crisps making (7%). Results indicated that slicing and drying and flour milling were the most commonly practiced due to low input and technical support requirement. While sorting and grading, and crisps making were the least practiced because sorting and grading led to difficulties of transporting bananas to the market and crisps making was considered more advanced technique which required more inputs.

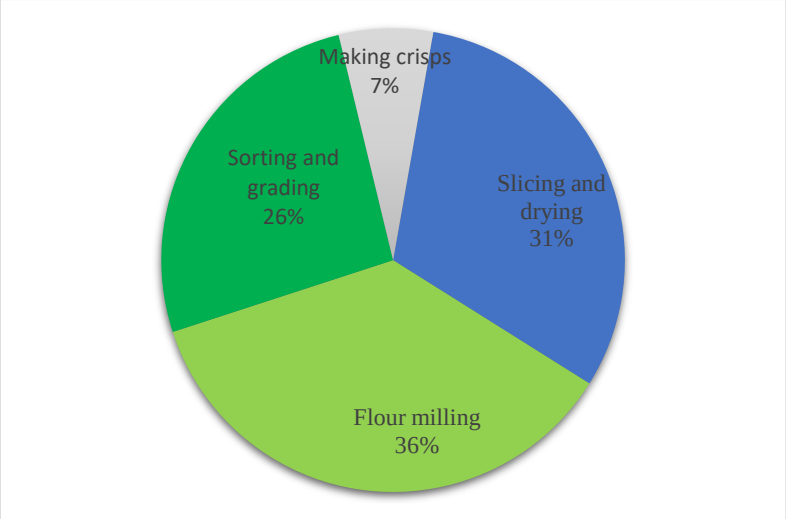

Figure 2. Banana value addition activities practiced in the study area

Socio-economic and institutional characteristics of small-scale banana agripreneurs

The characteristics of small-scale banana agripreneurs are presented in Tables 4 and 5. The results on categorical variables are discussed in Table 2 below. Regarding farming as the

primary occupation of agripreneurs, 67.16% of all the respondents practiced farming as their main occupation while 32.84% relied on off-farm activities as their main source of income. In addition, 88.52 % of value adders depend on farming crops and livestock as their main occupation for livelihood improvement, meaning these agripreneurs did not take part in off-farm activities and hence had no off-farm income compared to 57.86% of non-value adders. This enabled value adders to spend full time continuously taking part in value addition. There is a significant difference in primary occupation between the two groups at a 1% significance level.

About group membership, 89.05% of all agripreneurs were members of various agricultural groups. While 96.72% of agripreneurs who did not add value were members of the group compared to 84.71% of those who did not add value. This suggests that value adders were organized in the agripreneur groups than non-value adders. The difference was statistically significant at a 1% significant level. According to Orinda *et al*. (2017) group membership helps smallholder farmers to access the trainings and advice from various sources on agricultural technologies with ease.

The variable "type of roads" was broken down into earth, murram, and tarmac. Value adders accessed better roads compared to non-value adders. for instance, 78.69 accessed Murram roads compared to 62.14% of non-value adders who accessed earth rods to output markets. There was a significant mean difference on the type of road access to the market between the two groups at a 1% significant level. This finding is similar to a study which documented that improving rural road networks and infrastructure increases agricultural production as well as uptake of agricultural technologies (Maku *et al.*, 2022)

Table 4. Comparison of characteristics between banana value adders and non-value adders (Categorical variables)

Variable	Overall (%)	Value adders (%)	Non value adders (%)	Chi^2	P- value
Level of education of agripreneurs					
1= non-formal education	10.95	11.48	10.71	1.27	0.74
2= Primary level	28.36	22.95	30.71		
3 =Secondary level	40.80	44.26	39.29		
4=Tertiary level (college & university)	19.90	21.31	19.29		
Gender of Agripreneurs					
1 =Male	46.26	37.70	50.00	2.58	0.11
0= Female	53.73	63.30	50.00		
Marital status of agriprneurs					
1 =Married	80.10	78.69	80.71	0.11	0.74
0= Otherwise	19.90	21.31	19.29	19.88	
Primary Occupation					
1= Farming only	67.16	88.52	57.86	18.12	0.00***
0 = Otherwise	32.84	11.48	42.14		
Nature of the road					
1=Earth	46.27	9.84	62.86	116.80	0.00***
2 =Tarmac	26.37	11.48	32.86		
3 =Murram	27.36	78.69	5.00		
Group membership					
1=Yes	89.05	96.72	84.71	5.28	0.01***
0 =Otherwise	10.95				

Note: *** show that value adders and non-value adders differ significantly at 1%, respectively.

Further, characteristics of banana agripreneurs using continuous variables are presented in Table 5. Non-value adders had a mean age of 48.45 years while that of value adders was 45.05 years. And the difference was significant at 5%. This suggests that younger agripreneurs are risk-takers, more dynamic, and tend to try new ideas. This finding is similar to Kyomugisha *et al.* (2018) who reported that potato value adders were significantly younger than non-value adders in Uganda. This is in contrast to Ngeno *et al.* (2020) who found that older farmers have more experience and willingness to uptake agricultural innovations than younger farmers

The total land size owned by agripreneurs on average was 1.72 acres. However, the value adders owned significantly less land (1.55 acres) that non-value adders (1.80 acres). However, the land allocated to banana production did not differ significantly between value adders and non-value adders. Non-value adders have relatively large land sizes possibly because they have diversified their land with several crops and livestock production as an alternative source of income compared to value adders who may depend on bananas only as a source of income. This finding contradicts that of Musyoka *et al*. (2020)

Regarding production, 1,757.2 kilograms were harvested, on average. However, value adders harvested more (2,718.18) kilograms compared to their counterparts, who harvested (1,339.35)

kilograms. This finding supports Orinda *et al.* (2017) that farmers who added value to sweet potatoes and cassava respectively produced more output than smallholder farmers who did not participate in value addition.

Concerning the agricultural trainings received by agripreneurs annually, value adders received 3.23 trainings while non-value adders attended and 2.07 trainings and there was a significant difference in the number of agricultural value addition trainings received between treatment and control groups at 1% significant level. The significance of training among value adders is possible because value addition technologies are more complex and always need more labour hence requiring technical skills, experience, and knowledge. This finding is supported by Mkandawire *et al.* (2018) who deduced that trainings influence uptake of value addition positively and significantly.

There was a significant difference in the number of contacts with extension service providers between non-value adders and value adders at a 1% significance level. On average, one agripreneur received 2 extension visits per year. However, value adders received a mean of 2.64 extension visits while non-value adders received an average of 1.72 contacts. Access to extension services facilitates the dissemination of new knowledge and information and consequently affects the decision to embrace agricultural technologies by small-scale agripreneurs (Osondu *et al.*, 2023).

Banana agripreneurs who added live Kyomugisha *et al*. (2018) significantly further from output market than the non-value adders. The mean distance in kilometres for value adders was 7.21 kilometres whereas for non-value adders was 4.56 kilometres. There was a significant difference in kilometres covered by the output market between value adders and non-value adders at a 1% significant level. The distance to the market is used to determine whether an agripreneur can access the market hence the transaction cost. Far markets have better prices, therefore, value adders envisaged better prices in far distance markets for their products. The result is contrary to a study conducted in Uganda by Kyomugisha *et al*. (2018) that potato farmers who mainly added value were near the output market.

Table 5. Comparison of characteristics between banana value adders and non-value adders (Continuous variables)

Variable	Value adders (n = 61)		Non-value adders (n = 140)		Overall (n=201)		
	Mean	**Std. dev**	**Mean**	**Std. dev.**	**Mean**	***t-value***	**P-value**
Age of agripreneur (years)	45.05	11.57	49.93	13.78	48.45	2.42	0.02**
Household size (Number)	5.02	1.70	5.44	1.69	5.31	1.64	0.10
Farming experience(years)	20.79	9.88	22.54	9.74	22.00	1.17	0.25
Total land size (acres)	1.55	0.708	1.80	.784	1.720	2.14	0.03**
Area under banana (acres)	0.41	0.339	0.38	0.294	0.388	-1.00	0.43
Bananas harvested (Kgs)	2718.2	1565.9	1339.	1125.8	1421.4	-7.05	0.00***
Distance to output market	7.21	2.72	4.56	2.31	5.36	-7.08	0.00***
Extension visits (Number)	2.64	0.95	1.72	0.93	2.00	-6.40	0.00***
Trainings (Number)	3.23	1.12	1.56	1.37	2.07	-8.34	0.00***

Note: ** and *** show that value adders and non-value adders differ significantly at 5% and 1%, respectively. Std. dev = standard deviation

Determinants of utilization of banana value addition and extent of utilization of decision among small-scale agriprenuers

The Cragg's Double Hurdle model (DH), was used to simultaneously determine the factors affecting the decision of value addition in the first stage (first hurdle), and the extent of utilization of value addition in the second stage (second hurdle). However, it was critical to test the suitability of the Double Hurdle and Tobit model using the log-likelihood ratio test (LR). The LR recorded a value of 113.6 which was significant at a 1% significant level. This result led to the conclusion that the DH was more appropriate than Tobit model. The DH model recorded the log pseudolikelihood of -570.95 which was found to be significant at a 1% level of significance ($p = 0.000$) and the Wald Chi-square value was 59.73, showing the model fitted significantly better.

Determinants of decision to utilize banana value addition

Results of the factors influencing the decision to utilise banana value addition are shown in Table 6 The results show that the primary occupation of the agripreneur positively and significantly influenced the probability of embracing value-addition activities at a 1% level of significance. The likelihood of adding value increased by 144.33%, for farmers who had no other occupation compared to those with other occupations. This implies that agripreneurs whose main economic activity is farming have a higher likelihood to take part in value Those whose reliance is on farming as their main source of livelihood spend their full time on the farm hence producing more surplus for value addition. This finding is similar to a study which revealed that smallholder farmers who were engaged in farming adopted banana technologies (Barbra & Sam, 2020)

There was a positive and significant influence of quantity of banana produced on the decision to add value among agripreneurs at a 5% significance level. This indicates that the as production increases, this ensures more surplus will be available for value addition. This result is similar to Osondu *et al.* (2023) who stated that women farmers in Nigeria who produced more cassava had higher chances of participating in cassava value addition

Distance in kilometres from the agriprenuer's home to the output market was positive and significant at a 5% significant level. This plausibly means that agripreneurs who covered longer

distances to the output market from their homes had a higher likelihood to add value than those who stayed near the output market. As the distance from the agriprenuer's home rises by one kilometre, the propensity to add value to banana fruit increased by 18.91% *ceteris paribus*. The study corroborates with studies which suggested that dairy farmers who were nearer the marketplace, had lower chances of adding value to milk in Ethiopia (Beyene *et al*., 2017). However, the study's finding disagreed with Maku *et al.* (2022) the longer the distance to the market, the lesser the likelihood of youths to participate in maize value addition.

The type of roads for instance murram Road had a positive and significant effect on the decision to add value to banana and plantain at 1% level of significance. Road types were categorized as earth, murram, and tarmac roads. Access to Murram Road increased the probability of adding value by 241.33%. Murram roads are a type of rough roads with gravel. This type of road was better off than earth roads which are not passable during rain seasons hence having a positive coefficient. Road networks act as a proxy to access markets. They are a key factor in value-addition decisions because they enable goods to reach in the market in good condition and on time. Good road networks reduce transaction and transportation costs hence agripreneurs maximizing their profits. This result conforms with Maku *et al*. (2022) that developing rural infrastructure will improve agricultural production and further enhance uptake of new agricultural technologies in rural areas.

The number of agricultural value addition trainings received by agripreneurs had a positive and significant influence on the decision to banana value addition at 1% significant level. This means that with an increase in one training, the probability of undertaking banana value addition increased by 37.71%, keeping other explanatory variables constant. Trainings enable agripreneurs to get access to value-addition information, knowledge, and skills and also guarantees them the choice of the most profitable form of value-addition activities. This finding is similar to Kirimi *et al*. (2021) who stated that smallholder banana farmers from who received trainings were more likely utilize banana value addition in Kenya. However, the study concluded that these trainings were inadequate, therefore awareness creation on value addition could accelerate the adoption process.

Table 6. Tier 1: Probit regression estimates for determinants of banana value addition decision to utilize

Variables	**Marginal Effect(dy/dx)**	**Robust Std. Error**	**P>|z|**
Gender of the agripreneur (0= Female 1= Male)	- 0.229	0.361	0.525
Primary level of education (1 =Yes, 0= Otherwise)	-0.733	0.464	0.114
Secondary level of education (1 =Yes, 0= Otherwise)	0.221	0.465	0.635
Tertiary level of education (1 =Yes, 0 =Otherwise)	-0.328	0.663	0.620
Main occupation (1= farming, 0= Otherwise)	1.443	0.405	0.00***
Household size (Number)	0.115	0.120	0.337
Marital status of agripreneur (1 =Married, 0= Otherwise)	-0.517	0.414	0.211
Age of agripreneur (Years)	-0.008	0.017	0.656
Farm size owned (Acres)	-0.224	0.247	0.365
Quantity of banana fruit harvested in kilograms	0.000	0.000	0.029**
Number of trainings received (Number)	0.377	0.112	0.001***
Distance to the nearest market in kilometres	0.189	0.057	0.001***
Access to murram Road 1 =Yes, 0 Otherwise)	2.413	0.444	0.000***
Access to tarmac Road (1= Yes, 0= Otherwise)	0.093	0.436	0.831
Group membership (1= Yes, 0= Otherwise)	0.940	0.507	0.064*
Access to credit facilities (1= Yes, 0= Otherwise)	-0.609	0.316	0.054**
Access to extension contacts (Number)	0.628	0.213	0.003***
Constant	-6.218	1.361	0.000***
Number of observations = 201			
Wald Chi^2 = 59.73			
Prob> Chi^2 =0.000			
Log Likelihood = -570.95			

Note: ***, **, * denote significance at 1%, 5%, and 10 % levels, respectively,

Group membership was positively significant at 10% significant level. Being a member of a social group or cooperative, raises the propensity to add value to banana fruit by 93.99% *ceteris paribus*. This possibly means that being in a group or cooperative enables agripreneurs to easily receive incentives such as information, market and value addition technologies. This aligns with the finding of Tijani (2022) who stated that farmers who participate in groups tend to adopt tomato value-addition technologies as well as improved agricultural technologies respectively. However, the finding conflicts with that of Wondim *et al.* (2023) who found that cooperative membership had a negative influence on the adoption of value addition of fish processing in Nigeria.

Access to credit negatively and significantly influences the probability of banana value addition at 10% significant level. This possibly means that the more the agripreneurs easily obtain the credit, the propensity of adding value to banana fruit decreased by 60.89% keeping other explanatory variables constant. This possibly means that banana agripreneurs who received credit did not use it for value addition, instead, they used such credit to meet in other agricultural activities. This finding is contrary to Jacob *et al*. (2023) and Osondu *et al.* (2023)

The number of extension visits received by agripreneurs had a positive and significant influence on the decision of banana value addition at 1% significant level. Upon receiving one more extension visit, the probability of adding value to banana fruit increased by 62.81%. Banana agripreneurs get access to information on agricultural technologies through available

extension services. For instance, information on how to transform their raw banana fruit into other usable products (Osondu *et al.*, 2023). This finding is in line with Agoh (2021).

Determinants of extent of utilization of banana value addition

Truncated regression was used to analyse the extent of utilisation of banana value addition in step two (Tier 2). The extent was measured as the amount of banana value added in kilograms. The results are presented in Table 5.

Table 5. Tier 2: Truncated regression estimates for determinants of extent of utilization of banana value addition

Variables	Coefficient	Robust Std. Error	P>|z|
Gender of the agripreneur (1= Male, 0= Female)	-9319.92	7568.596	0.218
Primary level of agripreneur (1 =Yes, 0= Otherwise)	14651.14	13253.43	0.269
Secondary level of agripreneur (1 =Yes, 0= Otherwise)	20077.06	17049.54	0.239
Tertiary level of agripreneur 1 =Yes, 0= Otherwise)	19762.4	23411.44	0.399
Main occupation (1=farming, 0= Otherwise	7530.79	10926.58	0.491
Household size (Number)	-369.02	214.40	0.897
Marital status of agripreneur (1 =Married, 0= Otherwise)	-15490.03	8394.99	0.065*
Age of agripreneur (Years)	178.15	430.44	0.679
Farm size owned (Acres)	-369.02	6370.95	0.800
Quantity of banana fruit harvested (Kilograms per acre)	10.15	3.58	0.005***
Number of trainings received (Number)	307.89	4433.90	0.945
Distance from home to output market (Kilometres)	796.81	1468.02	0.587
Access murram Road (1 =Yes, 0= Otherwise)	9503.58	1468.02	0.455
Access tarmac Road (1= Yes, 0= Otherwise)	40221.17	12719.05	0.006***
Group membership (1 =Yes, 0= Otherwise)	34755.29	14762.52	0.290
Access to credit facilities (1 =Yes, 0= Otherwise)	-16554.71	32840.5	0.156
Access to extension contacts (Number)	9174.154	11662.07	0.027**
Constant	151698.50	4153.84	0.066*
Sigma constant	11505.5	82504.28	0.000***
Number of observations = 201			
Wald $Chi^2 = 59.73$			
Prob> $Chi^2 = 0.000$			
Log Likelihood = - 570.95			

Note: ***, **, and * denote significance at 1%, 5%, and 10% levels,

Extension contacts by agripreneurs from extension service providers positively and significantly influenced the kilograms of banana fruit value added at 5% significant level. The implication of this is that an increase in one extension contact would increase the volume of value-added bananas by 9174.15 kilograms, *ceteris paribus*. Extension contacts enable the promotion of value-addition skills through the transformation of information, trainings, workshops, and seminars. This finding is in agreement with the study of Musyoka *et al*. (2020) that that an increase in one extension contact increased the quantity of mangoes that were used in value addition.

The quantity of banana fruit harvested per acre determines the volume to value add. The quantity of banana harvested in kilograms positively and significantly influenced the extent of banana value addition at 1% level of significance. Addition of one kilogram of banana fruit harvested, the volume of banana fruit value-added increased by 10.15 kilograms. This plausibly means agripreneurs adding value, produced more bananas to serve for the surplus

used to add value. The result conforms with Orinda *et al.* (2017). While it contradicts with Oluwatayo *et al*. (2022) who documented more quantities of cassava harvested does not increase the extent of value addition because more quantities are wasted because it is a bulk and highly perishable crop.

The type of roads accessed by agripreneurs to output market was broken into earth, murram, and tarmac. Tarmac roads positively and significantly influenced the extent of banana value addition at a 1% significance level. The more agripreneurs accessed tarmac roads, the volume of bananas that was value-added increased by 40,221.17 kilograms. Roads are used as a proxy to access the markets. Well-constructed roads enable agricultural products to reach in the market faster and timely. This is similar to Maku *et al.* (2022)

Marital status (being married) had a negative and significant influence on the quantity of bananas value added at 10% significant level. A unit increase in the number of married couples decreased volume of bananas value-added by 15490.03 kilograms, *ceteris paribus*. This is possibly because married couples had more family members with many mouths that fed on bananas than singles. This finding is contrary to Okeke *et al*. (2022) who reported that married couples invested more in cassava value addition in Nigeria.

CONCLUSIONS AND RECOMMENDATIONS

Findings from the study highlighted the following conclusions. Compared to non-value adders, value adders were significantly younger, produced more quantities of banana, covered longer distances from their homes to output markets through access to murram and tarmac roads, received a higher number of trainings and extension visits and depend on farming as their primary occupation but they own smaller sizes of land and a few of them accessed the credit. Further, Slicing and drying and flour milling were the most utilized banana value addition activities in the area followed by sorting and grading and crisps making.

The current study provided information on the factors that influences the decision of small-scale banana agripreneurs to participate in banana value addition and the extent of participation decisions. The results revealed that different factors influenced decision to participate in banana value addition and extent of value addition.

The results indicated that the number of agricultural trainings, number of extension visits, group membership, quantities of bananas produced, farming as the main occupation, distance to the output market, and type of roads accessed significantly influenced the decision of agripreneurs to utilize or not to utilize banana value addition positively. While, access to credit had negative significant effect on decision to add value to banana fruit or not. On the other hand, number of extension visits, quantities of bananas produced, and type of roads had a positive and significant influence on the decision of the proportion of banana fruit value added. However, marital status (being married) had a negative influence on proportion of bananas value added.

Contribution of the study

The following are the contributions of the study to theoretical and empirical literature and insights to banana agripreneurs on status of banana value addition activities. Although this study was focused in Kisii county, Kenya, it has implications for developing countries, with an aim to improve banana value chain, promote food security and improved livelihoods of people through value addition. To the best knowledge of authors, literature on decision and extent of

banana value addition was not available. Therefore, this study provides an empirical contribution to the existing literature. The factors that influenced the decision and extent of participation in banana value addition could be explored in formulating and implementing policies and strategies geared towards promoting banana value addition agri-enterprises by improving the factors that could ensure sustainable utilization of these value addition activities.

Based on the study findings, the following recommendations were highlighted:

i. For relevant stakeholders, the government and developmental agencies to put in place policies geared towards promoting the use of banana value addition activities among agripreneurs, during formulation and implementation of such policies should put more emphasis on socio-economic and institutional factors that influence both decisions to utilize and extent of utilization of value addition. They include: extension contacts, quantity of banana produced and type of roads.
ii. The Kenya government should work hand in hand with extension service providers, Kenya Industrial Research and Development Institute officers in order to improve the provision of agricultural trainings offered to agripreneurs. Such trainings should involve farmer field schools, workshops, seminars, demonstrations and agricultural shows aimed at promoting as well as disseminating technologies about banana value addition.
iii. The government and private organizations should put in place policies to govern and manage the agripreneurs groups. These policies should ensure that agripreneurs receive services such as credit, trainings, value addition equipment as a group. This will enhance information sharing and creation of awareness on banana value addition innovations thus increasing the adoption process.

Suggestions of future research

This study was limited to institutional (Group membership, Access to credit, access to extension, extension contacts, Distance to nearest market, number of trainings, Experience in banana farming, road type) and socio-economic (factors Farm size in acres, main occupation Area under banana production in acres, Gender, Age, Education level, Household size) influencing the decision and extent of banana value addition in Kisii County, Kenya. The study therefore suggests further studies to be conducted as follows.

i. Future research may consider conducting a comparison study on the determinants of value addition in other developed or developing countries which are potential banana growing regions in the whole value chain among the small-scale agripreneurs processers, retailers, and wholesaler by including factors such as banana variety, perception, livestock equivalence, access to market information, household income, and other technological attributes such as accessibility, affordability, complexity and usability of the technology.
ii. Further study need to be conducted on effect of banana value addition on household income
iii. Another study can be conducted on consumer perception of value-added banana products and the factors influencing consumer acceptance and willingness to pay for such products.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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The Role of Policy Interventions in shaping the Four Dimensions of Food Security in select Developing Countries.

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Abstract

This paper systematically reviews literature on Food Security in Developing Countries, synthesizing the existing evidence and identifying the ongoing practices among those countries as they seek to address this widespread and pervasive issue. The literature reviewed is diverse and includes The Role of Agricultural Extension Officers in Production; Factors affecting Food Accessibility in low- and middle-income residential areas in urbanizing environments of Developing Countries; Urban Agriculture; Transition from Traditional Foods to modern ultra-processed foods in Food Utilization; and Economic, Environmental and Political factors affecting food stability so as to synthesize the existing evidence, and ongoing policy interventions. A systematic literature review was undertaken using Google Scholar and Science Direct, resulting in a final number of eight articles meeting the selection criteria. The studies revealed the variance in the challenges bedeviling the four dimensions of food security in the developing world. The uniqueness of the studies means that drawing any generalizations is inappropriate, rather, the specific cases should be treated specifically as they help understand the ongoing situations and practices. The paper reiterates the interlinkages among the four dimensions of Food security and reiterates that all the dimensions must be given equal attention. In conclusion, the paper highlights an aspect that is overlooked in current food security discourse, that is growth of the population. Population growth complicates the proposed solutions to the quandaries of food in/security. As population growth will certainly muddy the food security landscape, it is an evolution that must be addressed by ensuring sustainable and resilient food systems.

Keywords: Accessibility; Availability; Utilization; Stability; Population Growth

Introduction

Food security is a fundamental concept that entails ensuring that every person, at all times, has access to enough safe and nutritious food to sustain a healthy and active life. In addition to that definition, food security now encompasses four dimensions which are **availability, accessibility, utilization**, and the **stability** of food sources (Food and Agriculture Organization, 1996). From that understanding, food insecurity is a situation where one or a combination of the above-mentioned four dimensions cannot be achieved.

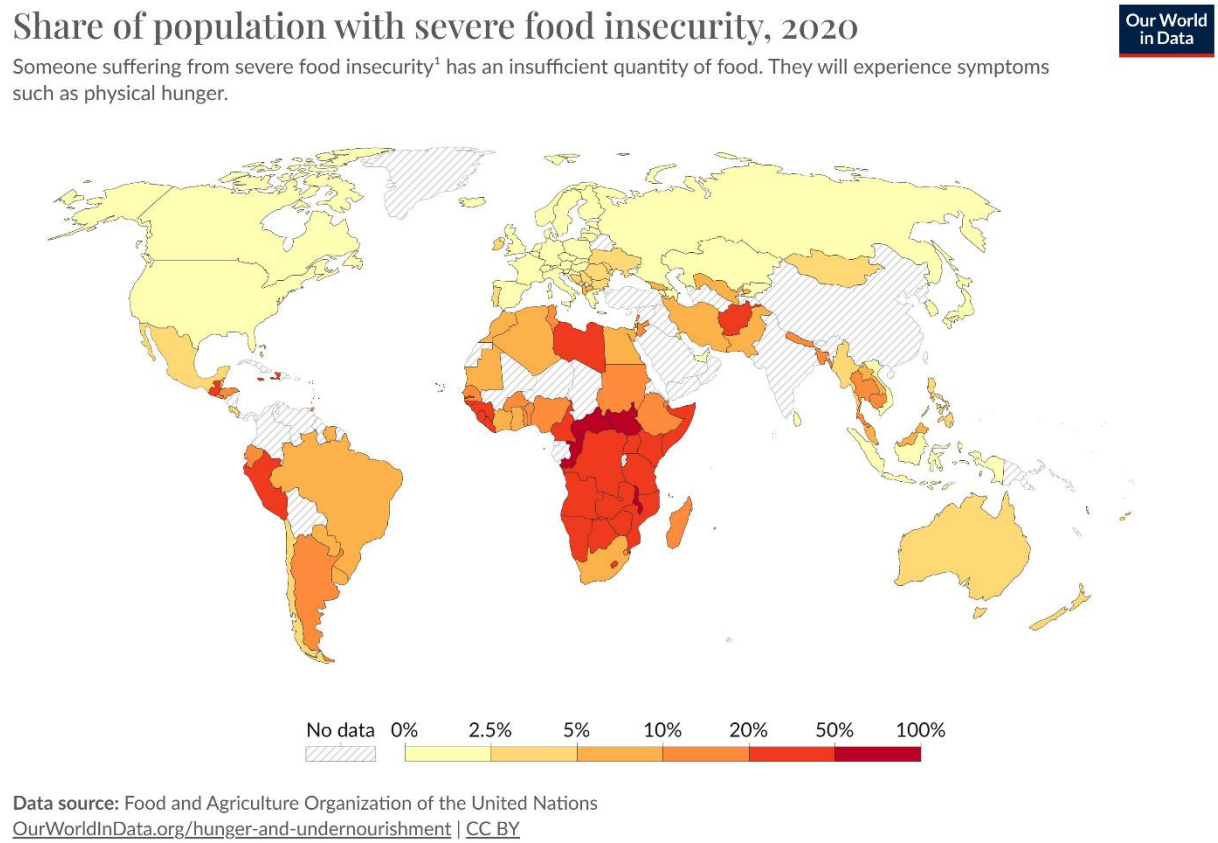
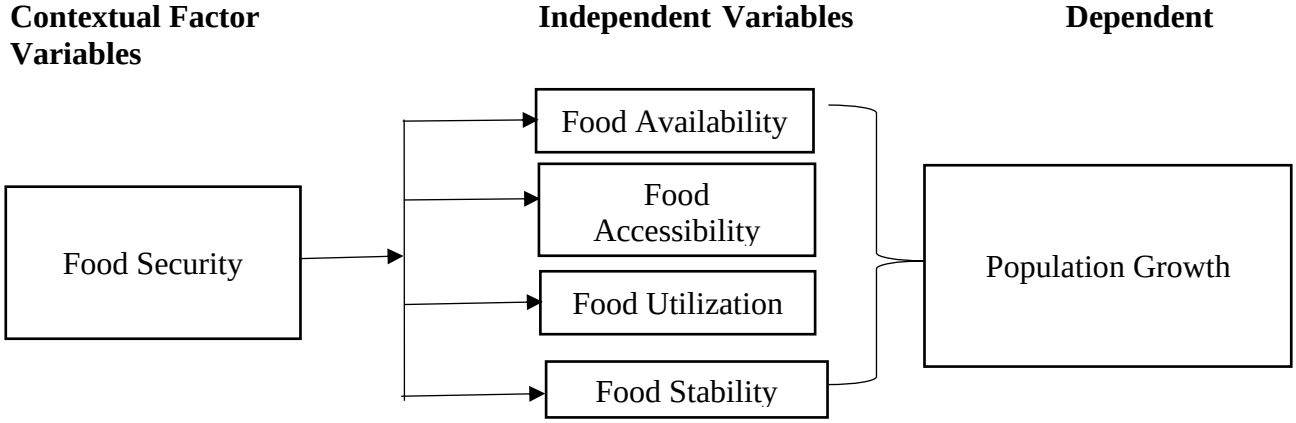


Figure 1: *A visual representation of the prevalence of food insecurity, and how the Developing countries compare to the rest of the world*

This paper desires to understand the food security phenomenon, and in so desiring, food security is viewed as the dependent variable, and the independent variables are the four dimensions of availability, accessibility, utilization and stability. Ultimately the paper underscores population growth as a contextual factor that should not be ignored in the food security discourse because it will greatly influence food security outcomes, in line with the Malthusian theory of Population growth. The aim of the paper is to examine the core factors that sustain the independent variables, and the policy interventions in place and their adequacy, to effectively pursue food security. Recognizing that food insecurity is a widespread issue, this paper draws from a few select developing countries, and occasionally looks at the situation in Kenya.

From the onset, it should be noted that food security is a complex and multi-faceted issue and the four considerations are interrelated and interdependent, rather than static and separate. (Berry et al., 2015)



Research Question

The central question guiding this systematic literature review is: What is the role of policy interventions in shaping the four dimensions of food security in select developing countries.

Methodology

This study used a systematic literature review (SLR) approach, which involved identifying and critically reviewing research findings with the ultimate end-goal of having a cross-cutting understanding of food security in a few select developing countries. In this paper I analyze different aspects of food security in developing countries.

Inclusion criteria

This study was not overly extensive, and did not draw from a wide range of literature. The inclusion criteria were also fairly broad and not rigid. Articles were subjected to a screening to determine whether they met predefined inclusion criteria. An article would be considered for this review if (a) it addressed food security concerns (b) the article must have been conducted or focused on any of the developing countries/regions and (c) the article must have discussed policy interventions. In the screening and information extraction, the main consideration was on the policy interventions proffered and their effectiveness, as against the factors affecting food security.

Food Availability

Food availability is the availability of sufficient quantities of food. According to Grote et al., it hinges upon domestic production and/or imports.

Productivity

Increased productivity of food crops ensures increased availability of household food. Increasing the productivity of farmers can be done through the application of appropriate knowledge in response to production challenges such as pests, diseases, and changes in weather patterns (FAO, 2017)

A surveyed literature by Raidimi & Kabiti, looks at sustaining food security by reviewing the role of Agricultural Extension Officers and training them. The literature holds that smallholder farmers are important drivers of the agriculture sector as they grow most of the food, and have become the mainstay of food supply for millions of people in South Africa, and that situation is likely to progress for several years, yet they are endowed with limited resources, including

inadequate education. The literature posits that Training and Extension Services is needed to ensure that farmers and other stakeholders can access appropriate skills for the development of agriculture as an industry, and is inadequately provided. The Extension Officers lack in professional qualifications; formal skills that address food security issues; communication skills; project management skills; computer skills; and people management and empowerment. Considering those shortfalls, improvements are needed in both pre-service (universities and colleges) and in-service training for extension agents, while training programmes need to emphasize new extension concepts and methodologies, as well as expand attention to marketing, communication, computer training, people management and empowerment, farm management, technical training, environmental issues, and the development of farmer and other client organizations. (Raidimi & Kabiti, 2019)

Grote et al also suggest that small hold farmers are very key in ensuring availability of food. They suggest that there should be investments and provision of public goods (i.e., infrastructure) by the governments to promote technological innovations adapted to smallholder needs. To further build on their case, they give an example in Ghana, where start-ups Farmerline and AgroCenta use mobile and web technologies that bring advice on farming, weather forecasts, market information, and financial information in different languages to illiterate farmers in remote areas. The new enterprise Sokopepe offers market information and farm record management services via SMS and web tools to farmers. They also give a Kenyan example where the start-up M-Farm offers pricing data to farmers to remove price information asymmetry.

In the coming decades, world agriculture will need to undergo major changes to meet the future food demands of a growing and increasingly rich and urbanized population and smallholders in developing countries play a key role worldwide in this food security (Fan & Rue). More than 80% (475 million) of the world's farms operate on less than two hectares of land. Although these farms account for only 12% of the world's farmland, they provide an estimated 80% of the food produced in Asia and in sub-Saharan Africa (SSA) (Lowder et al. 2014).

According to Abraham & Pringali, since the 1960s, economists have argued that crop productivity per unit of land declined with an increase in farm size and that has led to the emergence of the 'small farm paradigm', which states that there is an inverse relationship between farm size and productivity. They write that studies therefore conclude that small farms have an advantage over large farms in per capita productivity, due to higher labour utilisation (e.g. using family labour) and higher input utilisation (e.g. using intensive farming practices)

To this end and considering the empirical evidence in place, Governments need to equip their extension services with access to, and understanding of, a diverse portfolio of flexible farm-level interventions, with affordable technologies aimed at farmers with low capabilities or to increase yield (Gassner et al., 2019)

Importation

As things stand, a majority of developing countries are net importers of agricultural products. After COVID-19, the World Bank predicted that African economic growth would contract by -2.1 percent to -5.1 percent in 2020 (Arouna et al., 2020). Weakening African economies will therefore translate to weakening African currencies, which will raise the price of imports in local currencies, including food (Arouna et al., 2020). This only means that the first limb of food security, which is food availability will be difficult to attain through imports.

Kramer notes that when there are too many imports coming into a country in relation to its export, it can distort a nation's balance of trade and devalue its currency. The devaluation of a country's currency can have a huge impact on the everyday life of a country's citizens because the value of a currency is one of the biggest determinants of a nation's economic performance and its gross domestic product (GDP). Maintaining the appropriate balance of imports and exports is thus crucial for a country (Kramer, 2023).

Food Accessibility

The accessibility dimension looks at two angles. Firstly, that food can reach the consumer (transportation infrastructure) and secondly, that the consumer also has enough money for purchase (food purchasing power) (Peng & Berry, 2019). In a surveyed literature, research on factors affecting food accessibility was conducted on low- and middle-income residential areas throughout Accra, in Ghana. Results showed that educational attainment, household assets, and the demographics of a house-hold affect a household's ability to access food (fewer than 3% of household's source food from farming, gardening, or fishing, the ability to afford food thus ultimately underpins household-level food access). (Tuholske et al., 2020) The literature reiterates that higher educational levels, in case studies from around the world, have been shown to strongly correlate with decreased levels of poverty.

The above pattern is seen in other Urban centers as well. A research conducted in Kisumu, Kenya on Urban Agriculture by Opiyo & Agong found that only 14.5 percent of sampled households sourced food from their own production in the city. (Gassner et al., 2019)

According to Tuholske and colleagues, poorer, and less educated households regularly experience situations and anxieties related to the inability to access food. Should food prices increase, all else being equal, these households' food access situation will therefore likely worsen.

The economic status of households thus is a big determinant of food access as urban agriculture is quite insignificant as a source of food. (*Cup-Policy-Brief-No4.Pdf*, n.d.)

The work done by Opiyo & Agong, as cited by Gassner et al, thus suggests among others, the following policy issues, so as to ensure physical access and economic access:

i) Infrastructure and services: Policy should place food on the agenda of city infrastructural planning, including provision of fresh-produce markets with adequate food storage and preservation facilities, improvement of road transport networks, and integrated planning of food retail sites and transport nodes. The provision of affordable housing with requisite services also links directly to improved food security. The concept of food-sensitive urban design is an emerging trend and one that could prove a useful tool in ensuring a food-security-oriented planning response.

ii) Embrace the informal economy: The informal economy appears to be the primary source of food for most Kisumu residents, through the approved market areas as well as street vendors. All typologies of food vending play a critical role in enabling food access, particularly for the food insecure in Kisumu. Embracing the informal food sector implies more than acceptance, but also the provision of facilities such as adequate water, sanitation and storage facilities.

Food Utilization

The FAO defines this as "the proper biological use of food, requiring a diet providing sufficient energy and essential nutrients, potable water, and adequate sanitation. Effective food utilization depends in large measure on knowledge within the household of food storage and processing techniques, basic principles of nutrition and proper childcare" (FAO 2006:1).

Food utilization is reflected by the quality and diversity of diets (Grote et al., 2021). Grote et al, write that many people across the developing world still face challenges in terms of securing caloric intake and/or securing a diverse quality diet. That in countries such as Lesotho, Malawi, Zambia, or Zimbabwe, people cover large shares of total calories only with maize and micronutrient malnutrition thereby persists.

Among the four dimensions of food security, utilization is fairly cross-cutting, as even those living above poverty line may be lacking in food utilization. Traditional foods, such as dried or smoked meats and fish, dried beans, and maize meal, which were adapted to these lived conditions, are being increasingly replaced by modern ultra-processed foods, which are typically higher in sugar, fat, and salt than traditional foods (Thow et al., 2015). Substitution is determined by among others, the increasing importation of these foods, marketing and advertising, and increasing time poverty as urban commutes extend in length.

The transition has been studied in Southern Africa Development Community by Thow et al. where they conclude that there is significant intra-regional trade in products associated with the nutrition transition. In that study, they write that an increased access to processed foods and soft drinks within SADC facilitated by growing intra- and extra-regional trade and investment is a significant cause of the transition.

Without stifling trade, they suggest that the trade patterns in soft drinks and processed snack foods mean that regional policy action is needed to stem the flood of high calorie and nutrient-poor processed foods, snacks and beverages into the region, and thus contribute to reducing obesity and diet-related Non-Communicable Diseases.

With regard to marketing and advertising, the International Journal of Advertising called for papers to understand the power of advertising in society. Stafford and Pounders synthesized the papers received and whereas they noted that the collection noted that advertising has both positive and negative effects, they also appreciated that some may harm consumers in their overall well-being, because some advertisers may simply seek to sell a product with little regard to the consumer's best interests.

Concerning poverty, Siddiqui posits that Poverty contributes to malnutrition. Without adequate nutrition, human capital starts to decline because malnutrition negatively impacts physical and mental development, intellectual capacity, productivity, and the economic potential of an individual. A vicious cycle thus exists through which both poverty and malnutrition fuel and reinforce each other (Siddiqui et al., 2020). In the literature, they argue that it is imperative to intervene early in life in order to maximize the effectiveness of interventions and break the cycle. Interventions should be Nutrition sensitive, addressing intermediate and underlying causes of malnutrition and helping to improve access to nutritious food, clean water and sanitation, education and employment, and health care. These include interventions in the sectors of agriculture, social safety nets, early child development, education, and women's empowerment

Further they posit that community engagement need to reach the poorest of the poor to break the cycle of malnutrition and poverty and should also incorporate disease and infection prevention as a part of their strategy.

Stability

As a dimension of food security, stability pertains to the regularity of food supplies (Moseley & Battersby, 2020). Stability ensures that food can be accessed by individuals at all times (FAO, 2006). It is driven by economic, environmental and political factors (Grote et al., 2021). Chen considers the economic aspect and posits that Food security is guaranteed only when unexpected shocks, e.g., epidemics, and economic crises (job losses) can be well responded to.(Chen et al., 2023)

James Deaton & Lipka consider the political aspect and posit that Food Security is obtained through three primary pathways: food production, exchange for food, and food transfers (e.g., food aid). The effectiveness of each of these pathways requires institutions that successfully coordinate future expectations; hence, it is unsurprising that political instability and food insecurity go hand-in-hand. (James Deaton & Lipka, 2015)

Anderson considers the environmental bit, and posits that unpredictable variations in weather that influence agricultural productivity, the uncertain incidence of pestilence and natural disaster or the uncertain outcomes of human-determined farming processes affect food stability (Anderson, 2018).

The promotion of food system-based livelihoods and economic activity, environmentally sustainable practises and political stability are thus a crucial piece of the puzzle for moving towards greater food stability. Considering the above drivers of food stability (some can be prevented while some are more difficult to prevent), it is imperative to have more resilient households, communities and food systems.

Three aspects that define a food systems resilience approach are: (*Independent Dialogue | Food Systems Resilience in Protracted Crises*, n.d.)

- Firstly, it bridges the timeline cycle of relief, recovery, resilience and development. Addressing the awareness that humanitarian assistance is not a solution to ending food crises.
- Secondly, it takes a food systems perspective – based on an understanding that issues cannot be dealt with in isolation and solutions for programming lie in cross-cutting humanitarian-development-peace (HDP) approaches that respond to dynamics of food system behavior.
- Thirdly, it builds on the perceptions and existing resilience capacities of local communities and actors. By analyzing a food system and its resilience capacities together with local communities the approach breaks through aid siloes. While working with local actors in an evidence-based, adaptive approach ensures a good understanding of the interaction between food systems dynamics and resilience capacities as the programme is implemented.

Wageningen Centre for Development Innovation (WCDI) conducted a study to understand how food stability can be impeded by natural disasters. COVID-19 impacts were assessed in Ethiopia. Due to mobility restrictions, casual labourers were unable to travel to places where work was available and a robust social safety net for these groups was lacking. Other severely affected groups were the ultra-poor, acutely malnourished women and children. The response strategies were also assessed and the national response strategy prioritized crop production with a strong focus on cereals and cash crops. Those were selected for their ease and reliability of production, export value or import substitution value, but not nutritional value. Immediately, this shows that the utilization dimension was being compromised during the COVID-19 period and thus stability was impeded. Stability means that no food security dimension is compromised at any time.

WCDI recommended that monitoring can add to ongoing initiatives by including a focus on pro-active work through informing people to support their capability to anticipate and respond in such calamities. (*Fs-Cop201008-Hcss-52impact-Blackshore_report.Pdf*, n.d.)

Another study conducted in Adana, Turkey sought to understand the impact of economic factors on food stability. It found that food instability ratio in households was 69.1% to 39.6% for families with children and those without children. The study also found that poverty is the major cause of food instability and recommended policies that promote poverty eradication, such as educating and ensuring labour force participation of women. (Esturk & Oren, 2013)
A further study was conducted on developing countries to understand how political factors affect food stability. The study found that Food production and distribution activities, as well as the economy, will run well when there is political and security stability. Food will be available in large quantities, and people can access it easily. The study recommended maintaining political stability and the absence of violence. (Mulyo et al., 2023)

Population Growth: Contextual factor
Amidst the precarious food insecurity situation that developing countries are in, the population is also increasing. Simply put, if it is already challenging to feed the current population, what will happen when the population increases? The Malthusian theory on population growth provides answers on the relationship between population growth and food security, that whereas the former may grow exponentially, the growth of food supply and the supply of other resources is linear.

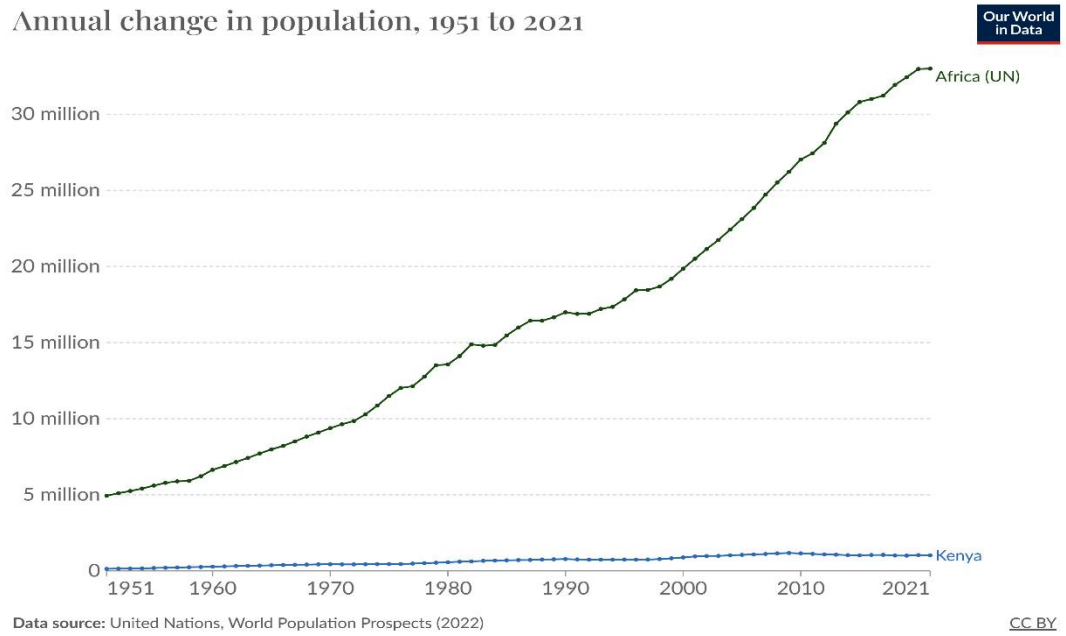


Fig. 1 The graph illustrates the dynamic changes in population for both Africa and Kenya, revealing distinctive trends and variations over the years(Ritchie et al., 2023)

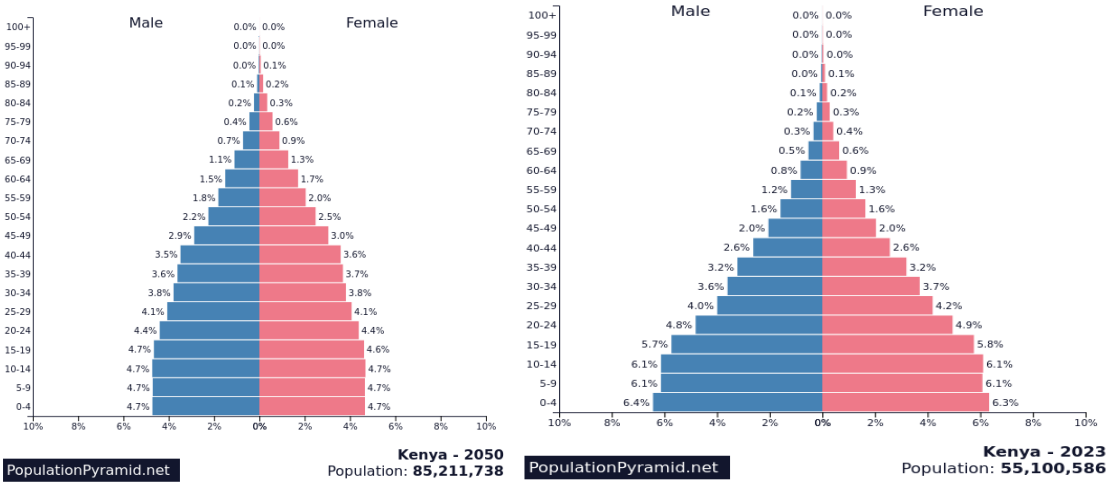


Fig. 2 Population pyramid for Kenya in 2023 and 2050 (*Population Pyramids of the World from 1950 to 2100 - PopulationPyramid.Net*, n.d.)

The population growth in the African continent has increased rapidly over the past two centuries and shows no signs of slowing down. In Kenya, since the turn of the twenty-first century, there is an average change of around 1 million every year. With that trend, the projection is that by 2050, the population is going to increase by another 30 million people, being a percentage change of about 50% and indicates a significant projected population increase. Rapid population growth will have implications for various sectors, including Agriculture and specifically food security, which is already a present concern. The total number of undernourished people in Africa has increased from 182 to 287 million, largely caused by the rapid growth in population. Further in middle Africa, the number of undernourished people has more than doubled since 1990 as a result of population growth (Hall et al., 2017).

According to a study by Hall et al, rapid population growth is the driving force behind food insecurity, which in that study, even overshadows the potential impact of climate change.

In a forward-looking manner, recognizing that food insecurity is only going to be more challenging as population increases, they suggest the following major solution:

a) Closing the yield gap.

Africa's yields have lagged behind most of the world. Most countries have achieved a significant rise since 1961. But across much of Africa, yields have stagnated. As a consequence the global inequality in yields has increased (Ritchie, 2022).

Hall et al., however warn that increasing yields is not a panacea to food security because if such an increase were possible, it may satisfy regional food security at present, but would not satisfy needs in the future, since production would not keep pace with the demand driven by population growth. It is therefore imperative that environmentally sensitive techniques are made an integral part of the intensification process and the most destructive practices are not carried into the future. In other words, the transition should be from 'intensification' to 'sustainable intensification.'

Conclusion

This study examined the dimensions of Food security, and placed the phenomenon in the context of population growth. It comes out that food insecurity can be experienced at various levels including regional, national, household, or individual. As per some of the studies conducted and policy issues suggested, it is clear that tackling food insecurity will require ingenuity, as the goal is sustainability. All the dimensions of food security must be sustainable and the pursuit towards food security should not only be about today but crucially about

tomorrow as well. For instance, rural urban migration is deemed to be an intrinsic part of success, policies that encourage urban to rural migration, and discourage rural to urban migration by opening up rural areas would unlock the key to sustainability, as urbanization is plainly unsustainable.

Further research should equally be conducted and policy formulation, implementation and evaluation be evidence-based and borrow from best-practises.

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Factors Influencing the use of Digital Technologies in the Marketing of Green Leafy Vegetables Among Smallholder Farmers in Lari Sub-County, Kenya

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Abstract

Smallholder farmers in emerging economies have long faced information asymmetry difficulties. To this day, the bulk of agricultural-related information is still conveyed by word of mouth, extension workers, or traditional broadcast strategies. Nonetheless, such information is often released irregularly and for a limited number of markets, leaving the vast majority ignored. As a result, market information becomes available to fewer individuals. Farmers decide to sell their produce through middlemen at relatively low prices, resulting in insufficient profits. Numerous studies have shown that digital technologies in agriculture are an important tool for farmers to be active participants in profitable markets by improving their access to timely and relevant market information. Despite the rapid expansion of digital technology in emerging nations' agricultural sectors, adoption of such technologies in rural areas remains low. The purpose of this study was to identify the characteristics that influence smallholder farmers' usage of digital technology in the selling of green leafy vegetables in Lari sub-County, Kenya. The study specifically attempted to determine the socioeconomic, institutional, and technological factors that influence smallholder farmers' usage of digital technology. A descriptive survey research design was used. A multistage sampling procedure was used to select 376 green leafy vegetable farmers. The semi-structured questionnaire was employed to collect data. A multivariate probit model was used to analyze the data. The results show that years of education positively influenced the use of social media in marketing, household size positively influenced the use of mobile phones and social media, and access to electricity positively influenced the use of mobile phones and the internet. Age had a negative influence on the use of the Internet in the marketing of green leafy vegetables. The adoption of digital technologies in the marketing of vegetables can be influenced by several factors. Therefore, the County Government through extension officers can provide training and education to smallholder farmers on how to use digital technologies effectively for marketing.

Keywords: Agricultural; mobile phone; social media; internet; information; socioeconomic

INTRODUCTION

The agricultural sector remains important for poverty reduction and contributes significantly to the majority of developing countries' economic growth (Eskia, 2019). This sector, which comprises countless small-scale farmers who generate over 80% of the food consumed in developing countries, also provides most rural households with either permanent or temporary employment. According to FAO (2022), Kenya's agriculture industry contributes around 33% of the country's GDP directly and another 27% indirectly through linkages with various other sectors. The subsector that exports the most is horticulture, and its growth continues to be key to the nation's economy. Cut flowers account for 70.3%, vegetables 18.1%, and fruits 11.7%

of the total horticulture export earnings in Kenya, making it the fastest-growing subsector of the country's economy (KNBS, 2022).

Kiambu County is one of the counties where horticulture farming is developing as a viable commercial enterprise. The sub-sector is crucial to the county's economic development (Kiambu-County-ADP, 2016) as vegetables are considered high-value crops because of their health benefits. The growth of the subsector is being driven by the increased nutritional value and health consciousness of consumers, notably for fruits and vegetables. French beans, snow peas, kale, cabbage, garden peas, tomatoes, spinach, and carrots are just a few of the popular vegetables grown in Kiambu. In 2022, exotic vegetables contributed 42.4 percent to the domestic value of horticulture in Kiambu. The area, production, and value were 158,567 Ha, 3.1 million tons valued at KES 72.65 billion respectively (AFA, 2022).

Spinach, kale, and cabbage are among the exotic vegetables that the majority of smallholder farmers in Lari Sub-County produce and market. The year-round rainfall and consistent low temperatures are favorable for vegetable growing. Vegetables, however, are prone to spoilage (Pokhrel, 2021). It is risky to handle large quantities of vegetables at the outdoor market, especially if growers lack refrigeration to keep excess produce. Consequently, they are unable to market their farm produce directly even though there is a ready urban market in Kiambu, Nakuru, Nairobi, and Mombasa (Kiambu-County ADP, 2016). Therefore, farmers are dependent on market intermediaries who buy their goods for less than market value. Inaccurate second-hand pricing information and a lack of market knowledge have major consequences for agricultural producers Deichman *et al.* (2016). Farmers risk having their produce wither away, being delivered insufficiently or excessively, or underselling their goods.

Market information asymmetry leads to substantial losses in profits (Zodidi, 2022). The use of digital technology would thus go a long way in bridging the market information gap between farmers and consumers (Jerome, 2017). According to Nwafor *et al.* (2020) and Okello *et al.* (2020), digital technologies are thought to have a significant impact on closing the information gap between farmers and markets. In Sub-Saharan Africa, Kenya has become a leader in information and communication technologies (ICT) (Baumüller, 2016). Kenyan farmers may get market and agricultural information on social media platforms including Mkulima Hub Kenya, Digital Farmers Kenya, and Mkulima Young (Kipkurgat *et al.,* 2016). Through social media platforms, farmers may exchange information and communicate with one another (Akashraj & Pushpa, 2014). Social media sites include Facebook, LinkedIn, Twitter, Instagram, and WhatsApp, to name a few.

ICT, such as the Internet for marketing, internet for information awareness, mobile application services, telephone communication, SMS services, radio broadcasting, and TV broadcasting are available in Kiambu County (Warwimbo, 2017). Despite this, most farmers have not fully embraced these new technologies hence they continue to lack full access to market information, impacting negatively their agribusinesses. It is however not clear why the uptake of these technologies remains low. This study therefore seeks to investigate factors that affect the use of mobile phones, social media, and the internet in the marketing of green leafy vegetables among smallholder farmers in Lari sub-County.

1. Literature Review

There are a variety of factors that can influence the use digital technologies by smallholder farmers (Jha *et al.*, 2019). These factors can be classified into categories, (i) farmers' characteristics; (ii) farm characteristics; (iii) technology characteristics; (iv) institutional factors; and (v) finance. They have direct and indirect relationships and influence the use of digital technologies either positively or negatively. Age, gender, and family income are just a few examples of the socioeconomic factors of smallholder farmers that have influenced how they utilize ICT, (Bryan & El Didi, 2019). However, Kante *et al.* (2016) pointed out that ICT's relative benefit, simplicity, compatibility, and observability also have an impact on smallholders' employment of the technology. According to Titilope (2020), smallholder farmers' slow adoption of ICTs may be caused by a variety of factors, including their poor income (or lack thereof), a lack of ICT infrastructure, their state of health, cultural differences, and other factors. Eskia (2019) and Nwafor (2020) claim that the poor adoption of ICTs among smallholder farmers is also a result of a lack of ICT awareness. According to Abebe and Mammo-Cherinet (2019), the key issues influencing smallholder usage of ICTs include limited energy supply, literacy, knowledge, and skills for running ICT applications.

The study conducted by Anthony revealed that the age of the household had a negative influence on the use of income. The implication is that relative to younger household heads, the older ones were less likely to use the internet. Ma *et al.* (2018) also pointed out that the authors argued that young people preferred to possess smartphones compared to older people. Okello (2017) stated that young farmers tend to be innovative and risk-takers and thus would try technologies more than older household heads. Older adopters of technology are usually slower at learning particularly if technology is relatively new.

Murage *et al.* (2015) found that male farmers adopt technology faster than female farmers. Therefore, men have more and easier access to ICT and more readily adopt technology. gender is an important variable in the adoption of innovations. When it comes to choosing which technology to use, the preferences of men and women differ. On the other hand, A big household size was often linked to a favorable effect on ICT use than a smaller household size, according to a study done by Sabuhoro *et al*. (2003) on factors that influence the use of computers by agribusiness owners in South Africa.

According to the reviewed publications, the education level of African smallholder farmers had a beneficial effect on their rate of technology adoption (Oyinbo et al., 2019). Smallholder farmers with some type of formal or informal education embrace new technology faster than illiterate smallholder farmers (Chirwa, 2005; Kassie *et al.*, 2015). Anthony *et al.* (2020) discovered that the off-farm job coefficient was positive and significant, indicating that families with an off-farm income used the Internet more than their counterparts. Off-farm income enabled farmers to acquire new technology like cell phones, which may improve their internet use.

Numerous studies have been undertaken on the usage, effect, adoption, and dissemination of digital technology by smallholder farmers, according to a review of the literature that is currently available. Researchers have attempted to determine the factors that affect smallholder farmers' usage of digital technology. The use of digital technology by smallholder farmers is still lower than anticipated, according to several prior researches. The poor uptake of digital technologies by smallholder farmers has been attributed to a number of challenges, including

a lack of awareness about digital technology, a lack of assistance from the government, a lack of digital infrastructure, a lack of help from banks, and problems with management. However, research on the use of digital technology by rural smallholder farmers in developing countries has been extremely limited. The preceding literature also reveals that there has been no major research on the use of digital technology by smallholder farmers of green leafy vegetables in Lari sub-County, even though such farmers are regarded as a productive basis of the Lari sub-County economy. As a result, this study has been conducted to bridge the gap.

2. Materials and methods

The study was conducted in Lari Sub-county, Kiambu County. Kiambu County borders Nairobi and Kajiado Counties to the South, Machakos to the East, Murang'a to the North and North East, Nyandarua to the North West, and Nakuru to the West and has a population of 2,417,735. The county is divided into four broad topographical zones; Upper Highland, Lower Highland, Upper Midland and Lower Midland Zone. The Upper Highland Zone is found in Lari sub-county and it is an extension of the Aberdare ranges that lies at an altitude of 1,800-2,550 meters above sea level. It is dominated by highly dissected ranges and it is very wet, steep and important as a water catchment area (Kiambu County CIDP, 2016). Lari sub-county is one of the twelve sub-counties in Kiambu County. The sub-county has five wards namely Lari/Kirenga, Kinale, Kijabe, Kamburu and Nyanduma Ward. It covers an area of 439.20 square kilometers. The constituency borders several other constituencies which include Githunguri Latitude and longitude.

The sub-county was purposively selected because majority of farmers practice agriculture as the main source of livelihood. Crops grown for sale in Lari include vegetables such as cabbage, coriander, spinach, and kale. Additionally, vegetable farming in the sub-county is largely favored by large amounts of rainfall received throughout the year and the continuous cold seasons. The area is relatively cold because of its location on the windward side of Aberdare Range. It receives a considerable amount of rainfall in a year. The majority of farmers in Lari own and use digital technologies like mobile phones. Some farmers have access to different social media platforms, and the internet search engines.

Kiambu County experiences bi-modal type of rainfall. The long rains fall between Mid-March to May followed by a cold season usually with drizzles and frost during June to August and the short rains between mid-October to November. The annual rainfall varies with altitude, with higher areas receiving as high as 2,000 mm and lower areas receiving as low as 600 mm. The average rainfall received by the county is 1,200 mm. The mean temperature in the county is 26°C with temperatures ranging from 7°C in the upper highlands areas. Furthermore, Agriculture is the predominant economic activity in the county and contributes 17.4 % of the county‘s population income. It is the leading sub-sector in terms of employment, food security, income earnings and overall contribution to the socio-economic wellbeing of the people. Majority of the people in the county depend on the sub sector for their livelihood, with 304,449 directly or indirectly employed in the sector. Coffee and tea are the main cash crops in the county. The main food crops grown in the county are maize, beans, pineapples and Irish potatoes.

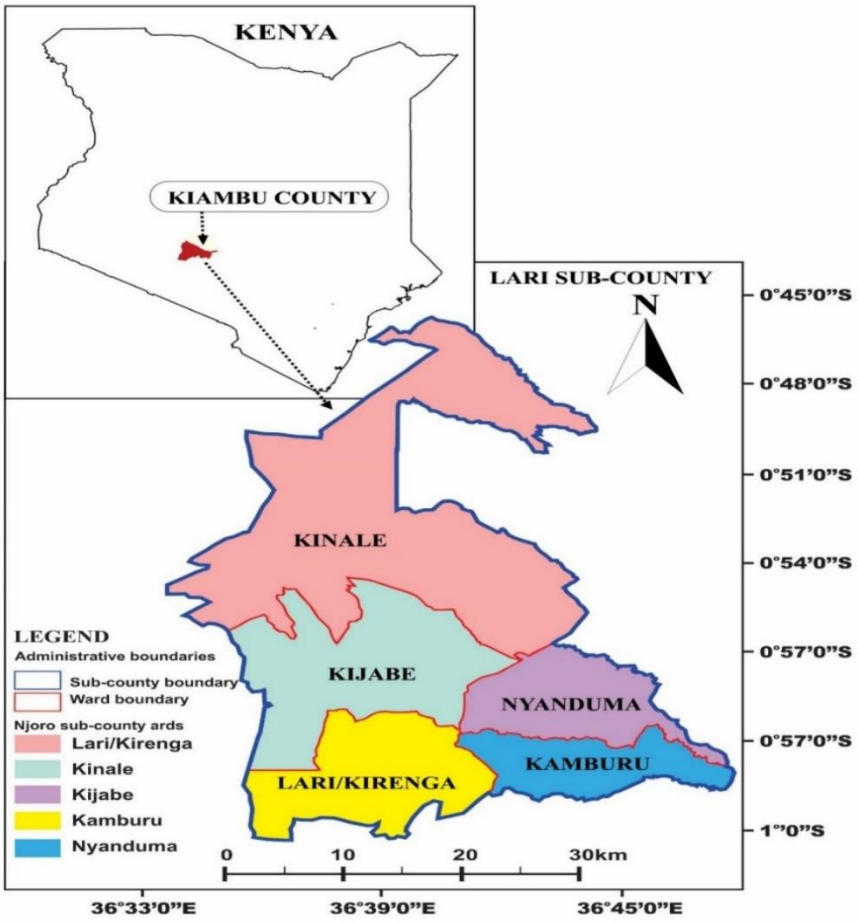

Figure 10. Map of Lari Sub-County, **Source:** IEBC (2022)

This study used descriptive survey design, since it enables both collection of qualitative and quantitative data without influencing the environment of the study, it also entails the descriptions of the attributes the target population exhibits, and hence its application is justifiable. A sampling frame was a list of 376 smallholder green leafy vegetable farmers. Ragab and Arisha (2018) define the sampling frame as the final list that represents the population which the researcher intends to select the sample from. The sampling frame of this study was obtained from Lari Sub-county agricultural extension officer**.**

A multistage sampling procedure was employed to select the respondents. Kiambu County was purposively selected for it is well known for its potential in agriculture, specifically the horticulture sector. The county is an important agricultural center, and it is under major seven vegetable-producing counties of Central Province. It is among the counties that have embraced the use of digital technology, more especially the use of mobile phones and social media in agriculture. In the second stage, Lari sub-county was selected purposively because it is dominated by smallholder farmers who grow vegetables like cabbage, spinach, and kale for sale. On the other hand, the majority of farmers in the sub-county own mobile phones, they have internet access, and social media platforms. Lastly, systematic sampling was employed to select the respondents from the five wards (Lari/Kirenga, Kinale, Kijabe, Kamburu, and Nyanduma) in the sub-county.

Determination of the sample size followed a proportionate-to-size sampling methodology as specified by Kothari (2004) using Cochran (1963) formula and was calculated as;

$$n = \frac{Z^2 pq}{e^2} \quad \text{.....1}$$

$$n = \frac{1.96 \times 1.96 \times 0.5 \times 0.5}{0.05 \times 0.05} = 384$$

where: n= Sample size; Z= Standard variation given confidence level of α= 0.05; p= Proportion of the population containing the major interest; q= 1- p and e = acceptable error or precision of 5%. Since the proportion of the population is unknown, p= 0.5, q= 1- 0.5= 0.5, Z= 1.96 and e= 0.05 (acceptable error term). This resulted in a sample of 384 respondents. The formula above is justified because the total number of smallholder green leafy vegetable farmers in Lari Sub-county is not known. Because of this, the assumption of the formula will be that 50% of the subject interest (farmers) possesses major attributes of interest for the study. The acceptable precision of 5% was chosen because of the smaller sample size and hence higher confidence level.

Table 14: Sample size distribution

Lari sub-county wards	Total Population	Proportion sample (%)	Sample
Kinale	26,007	21	81
Kijabe	27,627	22	84
Nyanduma	23,454	19	73
Kamburu	18,951	15	58
Lari/Kirenga	27,871	23	88
Total	**123,965**	**100**	**384**

Data was collected using a structured questionnaire. Piloting was conducted in Limuru, Limuru Central ward, to test for the validity and reliability of the tool. Data was organized into various categories, which are distinct from each other through coding, the data was then analyzed using SPPS version 29 and STATA version 17.

The objective of the study was to provide empirical evidence on the factors that influence the use digital technologies on the marketing of green leafy vegetables among smallholder farmers in Lari sub-County. The empirical specification of choice decision over the three digital tools can be modeled by either multinomial or multivariate regression analysis. However, the choices among the digital tools are not mutually exclusive as farmers are accessing information and use more than one digital tool at the same time and therefore the random error components of the information sources may be correlated. MVP was thus used to analyze the data. This model simultaneously models the influence of socio-economic, institutional and digital technology-related factors on each of the different digital tools while allowing the unobserved and unmeasured factors to be correlated (Lin *et al.,* 2005). This model would allow possible contemporaneous correlation in the choice to use the three digital tools simultaneously.

Empirically the model can be specified as follows

$$Y_{i1} = X_{ij1}\beta_1 + \varepsilon_{i1}$$

$$Y_{i2} = X_{ij2}\beta_2 + \varepsilon_{i2}$$

$$Y_{i3} = X_{ij3}\beta_3 + \varepsilon_{i3}$$

where, i = farmer identification, Y_{i1} = 1, if a farmer uses mobile phone to access agricultural information (0 = otherwise), Y_{i2} = 1, if farmer uses social media to access agricultural information (0 = otherwise), Y_{i3} = 1, if farmer uses the internet search engines to access agricultural information, marketing produce, and mobile financial services (0 = otherwise), X_i = Vector of factors affecting use of digital technology tools, β_j = Vector of unknown parameters (j = 1, 2, 3), and ε = the error term. Factors influencing the use of digital tools can be tested by running three different independent binary probit or logit models by assuming that error terms are mutually exclusive. However, the decision to use different digital tools may be correlated, thus the elements of error terms might experience stochastic dependence. In this situation, a multivariate probit model of the following form is used to test the hypothesis.

$$Y_{ij} = X_{ij1}\beta_1 + \varepsilon_{ij}$$

where Y_{ij} (j =1….,3) represents the three different digital technologies faced by the ith farmers (i = 1..…384), X_{ij1} is a 1 × k vector of observed variables that affect the choice decision of farmers, β_j is a k × 1 vector of unknown parameters (to be estimated), and ε_{ij} is the unobserved error term. Assuming the error terms (across j = 1… m alternatives) are multivariate and are normally distributed with a mean vector equal to zero, the unknown parameters in the above equation are estimated using simulated maximum likelihood. The method used Geweke Hajivassiliour-Keane smooth recursive conditioning simulator procedure to evaluate the multivariate normal distribution.

Table 15: Description and expected signs of the variables of hypothesized dependent and independent variables in the usage of digital technologies

List of variables	Description	Measurement	Expected signs
Dependent			
Usage of digital tool	Usage of digital tools to market and access information.	0 = Use mobile phone, 1 = Use social media, 2= Use the internet,	
Independent			
Age	Age of respondent	Continuous	+/-
Gender	Gender of respondent	Dummy 1=male, 0=female	+/-
Education	Education level	Continuous	+
Experience	Level of experience	Continuous	+
Household size	Household members	Continuous	+/-
Farm size	Size of the land	Continuous	+/-
Off-farm	Total off-farm income	Continuous	+
Awareness Level	Awareness of digital tool	Dummy 0 = aware of mobile phone, 1 = aware of social media, 2 = aware of the internet,	+
Access to Extension	Access to extension services	Dummy 1=yes, 0=no	+
Access to credit	Access to credit	Dummy 1=yes, 0=no	+
Distance	Distance to output Market (km)	Continuous	+/-
Access to electricity	Access to electricity	Dummy 1=yes, 0=no	+
Digital training	Training on digital technologies	Dummy 1=yes. 0=no	+
Relevance	Relevance of digital tool	Likert 1 = SD, 2 = D, 3 = N, 4 = A, 5 = SA	+/-
Accessibility	Accessibility of digital tool	Likert 1 = SD, 2 = D, 3 = N, 4 = A, 5 = SA	+/-
Affordability	Affordability of digital tool	Likert 1 = SD, 2 = D, 3 = N, 4 = A, 5 = SA	+/-

SD =strongly disagree: D = disagree: N= neutral: A =agree: SA =strongly agree

3.0 Results and Discussion

3.1 Socioeconomics and Institutional Characteristics of the Farmers

3.1.1 Farm and Farmers Characteristics

Table 3: Socioeconomic characteristics of the farmers

Characteristics	Description	Frequency	Percentage (%)
Gender	Female	145	38.56
	Male	230	61.17
Education	Adult Education	5	1.33
	No Formal Education	8	2.13
	Primary Education	151	40.43

Secondary Education	168	44.68
College Education	33	8.78
University	9	2.38

The results from Table 3 show that there are more male than female green leafy vegetable farmers in Lari. This means that more men are involved in farming activities. These findings are consistent with Chikaire *et al.* (2017) who found that males dominated farming and agriculture in general since they largely own the land and the decision-makers within the families. According to Sebotsa (2021), men are still more interested in engaging in agriculture using modern technologies than their female counterparts, which may explain the observed gender disparity.

The results on the education level of green leafy vegetable farmers indicate a variance in levels of education with a majority of farmers having secondary and primary levels of education. The majority of farmers had reached at least a secondary level, meaning that more educated farmers are engaging in agricultural activities and that they could be able to comprehend the value of utilizing modern agricultural technologies. These findings agree with Luqman *et al.* (2019), that smallholder farmers had access to literacy made it simple for them to comprehend agricultural information and implement modern farming methods targeted at increasing farm output. This implies that farmers are able to utilize the latest technology and evaluate information about their farms.

Table 4: Mean of the Socioeconomic Characteristics

Characteristics	**Mean Value**	**Std. Dev.**
Age	47.851	13.222
Household Size	6.495	2.430
Farming Experience	7.516	5.295
(Years)	0.5	1.178
Farm Size (Acres)	7,350	6035.13
Off-Farm Income (KES)		

According to the findings, the mean age of respondents was 48 years, which suggests that more young farmers are green leafy vegetable farmers, and they use modern technologies. The findings are in line with those of Okello (2017), who discovered that younger individuals were engaged in farming and used ICT in the best way possible in their agribusinesses. Younger farmers are potentially more innovative and risk-takers than older household heads, making them more inclined to explore new technology.

The survey's findings indicated that there are at least six people living in the household. According to Mdoda (2017), a household is more likely to engage in farming activities the larger it is since it is constantly trying to improve the amount of food available. The size of the household contributes to farm labor and supports the efforts of the household leader (Martey *et al.,* 2013). The availability of family labor enables the household head to divide his or her duties and free up time for other beneficial activities.

According to the findings, an average household marketing experience was at least 7 years. This indicates that the study area's farmers are capable of making sound decisions about marketing. Mdoda (2017) asserts that farmers with greater experience are more likely to

embrace agricultural practices that will increase their output and enable them to compete in marketplaces.

The average size of the land owned by the farmers was 0.5 acres. The results imply that majority of the farmers operate on small scale land. Farm size is a critical agricultural asset which have a bearing on production of a marketable surplus. Zodidi (2022) noted that farming households do farming on a relatively large land size; therefore, they could potentially produce for the markets and realize gains from trade.

The mean seasonal off-farm income of the households was KES7,350. Off-farm income is essential for the financial security of the smallholder farmers. Off-income can enable farmers to invest in technologies that facilitate access to market information, such as smartphones, and internet services. The higher the income of the farmer, the more likely he would seek and obtain information for use (Okello, 2017).

Farmers' Institutional Factors

Table 5: Institutional factors affecting the vegetable farmers

Characteristics	Description	Frequency	Percentage (%)
Access to Credit	Yes	167	75.23
	No	54	24.32
Extension Services	Yes	47	12.50
	No	328	87.23
Access to Electricity	Yes	333	88.56
	No	42	11.17
Digital Training	Yes	108	32.71
	No	253	67.29
		Mean	**Std. Dev.**
Distance (KM)		15.85	5.491

The results showed that majority of smallholder farmers had access to credit, while 24% did not have access to credit. This suggests that the households are able to acquire the agribusinesses' essential inputs, as well as bundles that enable them to utilize their digital tools. However, according to Zodidi (2022), most farmers who may obtain finance do so through informal institutions since smallholder farmers do not meet the criteria for formal financial institutions, which demand substantial collateral.

Additionally, the findings indicated that a larger percentage of smallholder farmers lacked access to extension services. This suggests that many smallholder farmers are unaware of new information and technology, as well as its advantages for agribusiness and product marketing. The findings are in contrast with those of Adejuwon (2018) and Oyinbo *et al.* (2019), who found that the majority of smallholder farmers had access to extension services. Farmers who use technology can access the agricultural knowledge they need through extension programs.

The availability of electricity is crucial for using digital equipment. The findings indicate that whereas a few percent of the respondents lacked access to electricity, the majority of respondents had electricity installed in their homes. The majority of digital technologies require power to function, hence access to electricity in homes is necessary for efficient use of these technologies. The findings are consistent with those of Okello (2019), who found that 70% of respondents had access to electricity, with TV viewers having the greatest accessibility. The

success of smallholder farmers' agribusinesses can be aided by training in digital technologies since it can teach them how to operate and use digital tools efficiently. 67.29% of the respondents said they had no prior exposure to digital technology, compared to 32.71% who had.

Distance between the home and the output market is frequently used as a stand-in for market accessibility and, consequently, transaction cost. The average household's travel distance to the output market was 15.85 kilometers. As households go further from the marketplace for their products, they utilize digital tools more frequently. These findings are consistent with those of Sekabira (2012), who discovered that families with limited access to agricultural markets because of distance and transportation costs have accepted the use of digital technologies.

3.0 Factors Influencing the Use of Digital Technologies in The Marketing of Green Leafy Vegetables

Table 4 presents the results of factors influencing the use of digital technologies in the marketing of green leafy vegetables from a multivariate probit model.

Table 4: Multivariate probit results for factors influencing the use of digital technologies

Variable	Mobile phone		Social media		Internet	
	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err
Age	-0.007*	0.004	-0.005	0.005	-0.010**	0.004
Gender	-0.263	0.198	0.014	0.205	0.102	0.193
Education	0.120	0.169	0.436***	0.170	-0.008	0.166
Household size	0.519**	0.245	0.497**	0.248	0.227	0.202
Land size	-0.099	0.067	-0.033	0.055	0.012	0.047
Off-income	0.000	0.000	0.000	0.000	0.000	0.000
Awareness	-0.116	0.308	-0.138	0.295	0.034	0.293
Experience	0.001	0.002	0.005	0.004	0.000	0.002
Extension	0.101	0.288	0.523*	0.281	1.273***	0.299
Training	-0.011	0.362	0.003	0.377	-0.254	0.340
Electricity	0.298***	0.111	0.098	0.110	0.480***	0.110
Distance	0.020	0.028	-0.004	0.026	-0.003	0.029
Accessibility	0.395	0.602	-0.655	0.610	-1.835***	0.687
Affordability	0.075	0.067	0.120	0.075	0.212***	0.071
Relevance	-0.073	0.143	0.019	0.126	0.087	0.132
Constant	-1.806	1.099	-4.386	1.200	-3.562	0.944
Number of Observations 375						
L. R. test of rho21 = rho31 = rho32 = 0: 0 $\chi2(3)$ =108.175 Prob > $\chi2$=0.0000						
Wald χ^2 (3) = 206.84 Prob > $\chi2$ = 0.0000						

The use of mobile phones and the internet was negatively impacted by the age of the household head, with each additional year decreasing usage by 0.7% and 1%, respectively. According to these results, households are less likely to utilize their mobile phones or the internet as sources of marketing and accessing market information as the household head grows older. Older household heads may be less likely to utilize modern digital tools like internet search engines since they may have grown up with less exposure to modern technologies. Once again, elderly

farmers may be less flexible, prefer traditional marketing strategies, and place a high value on traditional knowledge. The findings are consistent with those of Katunyo *et al.* (2018) and Mdoda & Mdiya (2022), who discovered that age had a negative effect on farmers' use of ICT. However, Zodidi (2022) found that age had a positive effect on the use of ICT, and concluded that the older the farmer, the more likely he/she is to use ICTs for accessing market information.

The household head's education level had a positive and significant impact on the utilization of social media as a source of market information and marketing strategy. This implies that with the additional year of schooling, the use of social media increased by 0.44 percentage points. The results show that exposure to education helps a single farmer to use social media platforms to successfully sell their products and build the capacity to retain and retrieve information relating to social media usage. Individual farmers may better themselves via education by learning how to look for and apply new information on improved farming practices and strategies for marketing. Farmers who have received an education are capable of reading and understanding content on social media sites. The findings are consistent with those of Okello (2017), who found that education significantly influenced the use of ICT tools.

The use of mobile phones (calls and SMS) and social media was significantly and positively influenced by household size. This suggests that the chance of using mobile phones and social media will increase by 51.9% and 49.7%, respectively, as household size increases. This could be due to the diverse skill sets in the families. The larger families often have members with diverse skills and interests. Some members can handle social media accounts efficiently, leading to more active online presence for the farm activities. In an effort to produce more, people may utilize their mobile devices and social media platforms to look up agricultural information. Once more, the demand for increased market communication, access to market information, and access to dependable marketplaces for the products may be the driving force for the use of social media and mobile phones in households with multiple members. Farmers who come from large families have an advantage since they may utilize some of their relatives to educate them on how to use technology. The results concur with Mdoda and Mdiya (2022) findings, which indicated that family size had a positive and significant effect on ICT usage.

Access to extension services was significant and it had a positive effect on the use of social media and internet search engines as a source of market information and marketing. Internet search engine and social media usage will rise by 0.52 and 1.27 percentage points, respectively, for every additional extension service. By encouraging farmers to share their thoughts and experiences and by lowering the cost of knowledge acquisition, extension workers promote innovation. The findings are in line with Tambo *et al.* (2019), who found that access to extension services is crucial for increasing productivity and applying innovation to the farm.

Access to electricity had a positive and significant effect on mobile phone and internet search engine usage. The findings show that families with electricity had a greater probability of using mobile phones and the internet by 0.3 and 0.48 percentage points, respectively. Electricity is needed for mobile phones, therefore having access to it would ensure their efficient operation. The results are consistent with those of Okello (2017), who found a positive correlation between mobile phone use and electricity installation. Nwafor *et al.* (2020) also revealed that an inadequate electricity supply decreases the farmers' marginal use of ICTs.

The accessibility of information through digital tools had a negative and significant effect on internet search engines at a 1% significance level. The likelihood of utilizing internet search engines declined by a proportion of 1.84 as information became more readily accessible.

Farmers may have trouble using search engines and navigating the internet successfully because they lack digital literacy, which might be the cause of this. The impact of accessibility on mobile phones, however, was positive and significant, according to the findings of Okello (2017).

3. Conclusions and Recommendations

The purpose of this paper was to investigate the factors that influence the use of digital technologies in the marketing of green leafy vegetables among smallholder farmers in Lari sub-county. In achieving the objective, the multivariate probit regression model was used, and the results indicate that the majority of smallholder farmers were using mobile phones, followed by social media, the internet search engines. The multivariate probit results showed that years of education positively influenced the use of social media in marketing, household size positively influenced the use of mobile phones and social media, and access to electricity positively influenced the use of mobile phones and the internet in the marketing of green leafy vegetables. Age and accessibility of the information had a negative influence on the use of the Internet in the marketing of green leafy vegetables. The study therefore concludes that the use of digital technologies can either be negatively or positively influenced by various factors. Therefore, the study recommends that the government, with the assistance of extension authorities, start more informational programs to encourage smallholder farmers to adopt digital technologies for agricultural marketing and accessing information. Factors like age should be considered when the new technology is introduced.

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Factors Influencing the Sustainability of University-incubated Agribusinesses; A case of Stigma Failure, Personality and Motivation Factors

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Abstract

Universities, government bodies, and non-governmental organizations have invested in incubating agribusinesses within universities to enhance youth employment opportunities since universities are major institutions channeling youths to job markets. However, many of these incubated agribusinesses (IB) struggle to survive beyond three years. This study sought to understand the factors that motivate university students to join university incubation programs (UIP) and the impact of these motivation factors on the economic, environmental and social sustainability of their agribusinesses. Principal Component Analysis (PCA) was used to create dimensions in the motivation factors, revealing the 2 Principal Components. Findings reveal that the majority of university students take the initiative to participate in UIP because they have a need rather than seeing an opportunity. The two components, together with stigma failure and personality, were analysed in the Structural Equation Model under Partial least square methods. Findings reveal a positive and significant relationship between necessity motivation factors and the sustainability of IB ($p= 0.000$), as well as a positive and significant relationship between personality/behavioural factors and the sustainability of IB ($p=0.000$). However, it was found that opportunity motivation factors had no significant relationship to the sustainability of (IB) ($p= 0.831$). This study suggests that university policymakers should institutionalise UIP. University business incubators (UBI) should understand the need for their incubates before the incubation process. As they develop the incubation models, holistic attention is needed for all business sustainability factors, including the personality of the students to be enrolled.

Keywords: Business incubation, Agribusiness, Sustainability, PCA, PLS-SEM,

Introduction

More than a third of Kenya's youth eligible for work have no jobs in a general business environment where the government struggles to tackle the country's acute unemployment problem (Alushula, 2020). This youth unemployment situation has forced the government and non-governmental organizations to mitigate this problem by incubating youths through entrepreneurship skills and providing start-up capital on certain occasions (Ferreiro *et al.*, 2018). Business incubation is a process that provides space, mentoring, and support services to high-potential entrepreneurs as they develop their ideas into viable and feasible businesses. However, despite these organisations providing funding and support to youth agribusinesses, many of the funded and supported agribusinesses tend to cease or fail the moment the project funding stops, while others, even after incubation, fail to start (Yoshino & Taghizadeh, 2016); that is to say, they are not sustainable.

Business sustainability is the ability of an agribusiness to maintain its objectives while standing on its own, as well as posting a positive cash flow without compromising resources for future generations. (Purvis *et al.*, 2019; WCED, 1987; Zapata-Guerrero *et al*., 2021). On the same

note, literature from Schwartz (2011) on long-term incubated firm performance after graduation indicates that incubated firms tend to exhibit a high growth rate during the incubation period. Afterward, during the postgraduation period, they reveal potential negative effects of the discontinuation from the support and incubation where many of them do not survive, hence creating a question of why others survive while the rest fail.
The interest in the university-sponsored business incubator stems from the potential of the concept that holds out the possibility of linking talent, technology, capital, and know-how to leverage entrepreneurial talent, accelerating the development of new technology-based firms, and speeding up the commercialization of technology as also stated by Wachira (2017). These facilitate the creation of job creators other than job seekers and more skilled personnel needed in the job market (Hassan, 2020; Segosebe *et al.,* 2020). Thus, universities are one such parent organization for incubators that can be a pivotal joint in mitigating unemployment in the country (Aebischer, 2015).

It still stands as a challenge as many of the incubated agribusinesses fail to start after being incubated, while others that start fail to continue the moment the support stops. Therefore, this study focused on understanding the factors influencing the sustainability of youth-led incubated agribusinesses in universities of Kenya to contribute to the knowledge gap of why many of the incubated agribusinesses fail to start after being incubated while others that start fail to continue the moment the incubation and support stops.

Literature review

Starting up businesses' motivations can be complicated, and they frequently have a close connection to the entrepreneur's personal life and those of their family. (Molina, 2020; Shahzad, *et al.,* 2021). Considering small and medium-sized businesses (SMEs), the literature suggests that individuals are pulled or pushed into business (Gódány *et al.,* 2021; Patrick *et al.,* 2016; Van der Zwan *et al.*, 2016). Adapting the research results of the Global Entrepreneurship Observation Report for this study, push and pull motivation are distinguished by introducing the concept of opportunity and necessity entrepreneurship (Ismail *et al*., 2016;).

Necessity entrepreneurship refers to nonoptional or enforced entrepreneurial activities when someone has no alternative due to personal reasons or certain conditions. Opportunistic entrepreneurship refers to the entrepreneurial activities that someone engages in to pursue personal ideals because of business opportunities discovered (Aima *et al*., 2020). Researchers such as Van der Zwan *et al.,* (2016) also mention mixed motivation. In this situation, individuals start businesses because of both motivations, that are to say, necessity and opportunity motivations at play. Van der Zwan *et al.,* (2016) also mention mixed motivation, a situation where individuals start businesses because of both motivations, that are to say, necessity and opportunity motivations at play.

Push motivation, which is often related to the unemployment-push effect, has been provided in several studies (Granger *et al.,* 1995; Kirkwood, 2009;). These studies argue that unemployment lowers the opportunity costs of self-employment, thereby driving individuals to start their businesses. In addition, Van der Zwan *et al.* (2016) also mention push motivations as a result of autonomy and family pressure pushing individuals into the direction of new venture creation. Giacomin *et al,* (2007) distinguish between three pull motivations: market opportunity, social status, and profit. Jayawama *et al*. (2013) and Van der Zwan *et al.,* (2016) provide evidence of many pull motivations, including the need for approval, independence, personal development, improved welfare and wealth, and following role models.

On the same note, some entrepreneurs are neither driven by pull nor push motivations (Giacomin *et al*., 2007). Therefore, a group of individuals may take entrepreneurship as a hobby. The influence of these motivations on performance and entrepreneurial engagement has been discussed by Van der Zwan *et al.,* (2016), who found out that more individuals take the initiative to start a new venture because they see an opportunity than a need.

Research conducted by Nsengimana *et al.,* (2017) discovers various reasons why women SMEs in Rwanda fail to be sustainable. Among others, they identify youths aged 18–48 years as being more energetic and active. They can better withstand the demands of running a business than their older counterparts. Access to starting and operating finance remains the most significant challenge for their creation, survival, and growth (OECD, 2014). Watson *et al*. (1998) also identify some of these reasons why most SMEs fail to be sustainable; however, they may not apply to the youths, particularly in universities, as they tend to be of different age groups with different responsibilities.
With views from a study, organizational factors influencing the sustainability of local non-governmental organisations. Okerley and Nkrumah (2012) explain that the availability of funds, quality material resources, supportive leadership, development of needs-based and demand-driven programs, and effective management can significantly influence the sustainability of local NGOs. Their study highlighted leadership availability and quality of material resources for work emerged as crucial factors in organizational sustainability. On the same note, researchers such as Jagadeeswari *et al.* (2020) disclose that Innovation, risk-taking, Tolerance, self-efficacy, Financial Control, Opportunity Identification, Self-Efficacy and Managerial Self Efficacy significant traits for entrepreneurs for sustainability of their ventures bringing in a concept of entrepreneur personality or behavioural characteristics as a factor influencing their venture sustainability.

In the current study of this article, factors influencing the sustainability of university-incubated Agribusinesses considered include personality/behavioral factors, necessity and opportunity motivation, as well as stigma failure. The universities under study included the University of Nairobi, Kenyatta University, Strathmore University, Jomo Kenyatta University, Egerton University, Moi University, and Riara University.

Theoretical Framework

The study considered two theoretical frameworks: the Resource Based theory by Madhani (2010) and as expounded upon by Alvarez and Busenitz (2001) in terms of cognitive ability and Corporate Sustainability proposed by Chang et al. (2017). These theories suggest that resources that are valuable, rare, difficult to imitate, and no substitutable best position a firm for long-term success. These strategic resources can provide the foundation to develop firm capabilities to sustain itself and acquire a competitive advantage. Despite that, entrepreneurs have individual-specific resources that facilitate the recognition of new opportunities and the assembling of resources for the venture. (Alvarez and Busenitz, 2001; Madhani, 2010). These theories are relevant because whether the individual joined incubation programs by need or by opportunity, the individual wanted to turn the resources into a business.

On the other hand, Corporate Sustainability was operationalized through the Triple Bottom Line (TBL), a concept developed by Elkington, (1997). While Corporate sustainability is based on adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining, and enhancing the human and natural resources that will be needed in the future, TBL suggests that an organization can facilitate its movement

toward sustainable development with a management approach that integrates social, environmental and economic/ financial. In this case, the study aimed at the overall sustainability of the incubated agribusiness, including the effect of the business on the green environment while ensuring the economic sustainability of these agribusinesses.

Methods

The study was conducted in seven major selected universities in Kenya which incorporate both public and private universities with business incubators which include the University of Nairobi, Kenyatta University, Strathmore University, Jomo Kenyatta University, Egerton University, Moi University, and Riara University. Using the multistage sampling technique, the sample size was purposively selected from these selected universities, whereby the administration of each particular university was approached for the known registered incubators within that given university. The given incubators were then approached to provide lists of youth(s) agribusiness groups and contacts that participated in UIP. The final respondents were selected from the given lists provided by the incubators through a simple random sampling technique. Therefore, for this study, Cochran's (1963) formula for determining populations that are large and unknown was used to determine the sample size;

$$n = z^2 \frac{p(1-p)}{e^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

Where; n_0 is the sample size, z^2 is the abscissa of the normal curve that cuts off an area at the tails, (Z-score of 95% from the table, which is 1.96), e is the margin of error (confidence interval/ the desired level of precision) of +/-5%, p is the estimated proportion of an attribute that is present in the population (standard deviation). According to Israel (1992), p= 0.2 is used in situations where a majority of the population may not have the attribute of interest. Thus, to get the sample size, this study assumed p to be 0.23 due to the fact that a smaller number of incubated businesses may last for more than three years when they are not sustainable and may exist by name or in debt but not as a business that can stand on its own (Wedig & Wiegratz, 2018) Thus,

$$n = 1.96^2 \frac{0.23(1-0.23)}{0.05^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 2}$$

$$n_0 = 272 \text{ respondents}$$

The 272 respondents were distributed equally between the seven selected universities of Kenya that is to say; a minimum of 39 respondents from each university. However, since the study considered only agribusinesses, some of the universities were not in a position to provide a full number of 39 respondents (students incubated in agribusiness). Therefore, the study maximized universities with a larger number of university-incubated agribusinesses.

Table 16: Distribution of Respondents

S/n	Universities	Incubators	Number of respondents	Percentage
1	University of Nairobi	C4DLab	19	6.9%
2	Kenyatta University	Business Incubation and Acceleration Centre	50	18.4%
3	Jomo Kenyatta University	JKUAT industrial Park	40	14.7%
4	Egerton University	CoELIB and AGLEAD	50	18.4%
5	Strathmore University	Strathmore Enterprise Development Centre (SEDC)	39	14.3%
6	Moi University	PTRE Incubation Centre	40	14.7%
7	Riara University	Accelerating Entrepreneurship Support in Universities in Kenya (AESU)	34	12.5%
TOTAL			**272**	**100%**

Note: The numbers sampled, as indicated above were retained after data cleaning

The study employed a survey research design. Data collection was carried out from primary sources, representing several business incubators in seven recognized universities. This primary data was collected through interview schedules in a few cases and questionnaires through online surveys and phone calls since respondents were quite far from reach. Phone calls and links to an online questionnaire were made and shared by trained enumerators. The study used the Statistical Package for Social Sciences (SPSS), STATA, and Smart PLS version 4 for analysis.

The driver's motivation instrument used in the investigation had 20 composition items which were rated on a 5-scale point with 1 indicating disagree and 5 indicating strongly agree. The statements were essentially statements representing underlying student motivation to participate in university incubation programs either with a motive to take advantage of incubation as a business opportunity or the individual felt that there were no better choices for work after school even as considered for opportunity and necessity motivation by the Global Entrepreneurship Monitor GEM (Linan et al., 2013). Thus, the study considered Principal Component Analysis (PCA) an explanatory analysis useful for investigating dimensions (Hair *et al*., 2006).

Before PCA, assumptions of multivariate data analysis, namely; normality, homoscedasticity and independence of observation, were tested (Hair *et al*., 2006). The multivariate normality test produced statistically significant results at prob>chi2= 0.0000. While the Kaiser-Meyer-Oklin Measure of sampling Adequacy was 0.829 and Bertlett's Test of Sphericity was also statistically significant at 0.000. In addition, reliability analysis was performed on each factor for evidence of internal consistency and discriminatory reliability. Throughout the analyses, the items to be retained were selected on the following basis;

i. The factor solution was constructed using the criterion of eigenvalue being greater than 1.00,
ii. Factor loading was not less than 0.4 based on the factor loadings guideline for the sample size of 200 (Hair *et al*.,2006),

iii. The minimum number of items per dimension was 4 and any dimension that loaded fewer was removed. However, no dimension loaded 0.60 was to be retained.

iv. In the case of cross-loadings, the item content was scrutinized to see the factor that best describes that item.

In general, the first analysis was characterised by: i. A chaotic distribution of items across the factors, ii. Factorial complexities, and iii. The existence of items with very high loadings in unreliable factors. Thus, to obtain valid and reliable subscales, problematic items indicated by item-total correlations were identified and reanalysed to assess the reliability and common variance shared by the items, whereby in each analysis, the total variance explained exceeded 50%. The results suggested that most items with factorial complexities needed to be deleted. Results also revealed that when many items were deleted, the communality of a few other items was also affected. Finally, 9 items had to be deleted, and 11 items were retained, which formulated 2 principal components. Only results from the final PCA are reported in this article.

The retained results from PCA were thus used in the Structural Equation Modelling (SEM) under Partial least square methods (PLS) to determine the motivation factors influencing the sustainability of university-incubated businesses. Other factors considered for the PLS-SEM model included stigma failure and personality/ behavioural factors. The personality of students who participated in UIBs was measured with statements that investigated Risk-taking propensity, Self-efficacy, Internal locus of control, Proactiveness, Autonomy, Innovativeness, optimism and competitiveness. These instigative statements were measured on a Likert scale, with 1 representing strongly disagree and 5 representing strongly agree. On the other hand, economic, environmental and social sustainability were also measured on a Likert scale with dimensional statements that investigated each dimension. Likewise, 1 represented strongly disagree and 5 represented strongly agree. The PLS-SEM model using path analysis was used for model estimation during the analysis considering 3 hypotheses as follows;

i. **H1;** There are significant direct and indirect effects of necessity motivation (comp 1) factors on the economic, environmental and social sustainability of the university-incubated business
ii. **H2;** There are significant direct and indirect effects of opportunity motivation (comp 2) factors on the economic, environmental and social sustainability of university-incubated business
iii. **H3;** There are significant effects of the personality of students participating in university incubation programs on the economic, environmental, and social sustainability of their agribusinesses

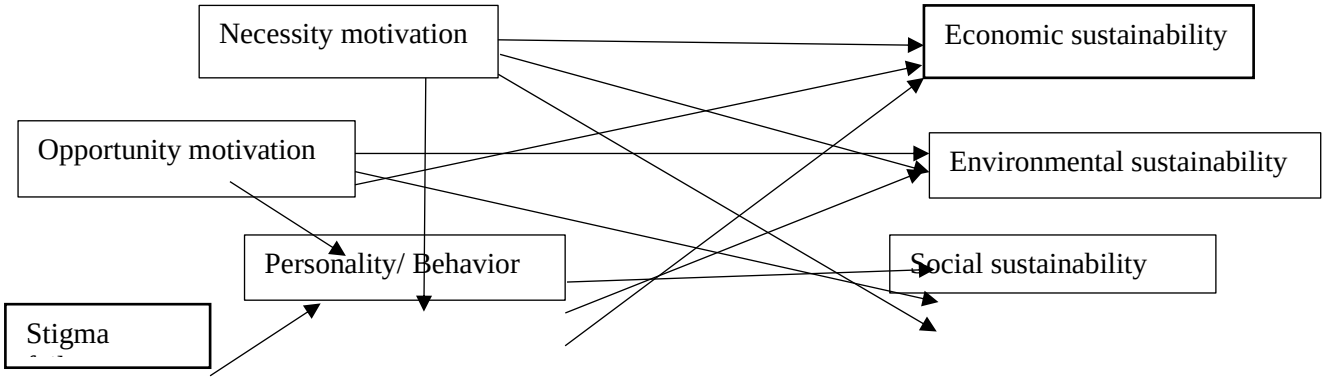

Figure 11 Conceptual framework

Results and discussions

Results in Table 2 reveal the final analysis where 11 items underwent PCA with oblique and varimax rotations to extract 2 components whose mean ranged from 2.20 to 4.06. The multivariate normality test produced statistically significant results at prob>chi2= 0.0000. While the Kaiser-Meyer-Oklin Measure of sampling Adequacy in Table 3 was 0.829, and Bertlett's Test of Sphericity was also statistically significant at 0.000 (Hair *et al*., 2006). This meant enough variance in the data that could be portioned using PCA (KMO >0.5). On the same note, the items had a good correlation since the P-value was smaller than 0.05, and thus data was fit to be submitted to PCA analysis. Results reveal that all the 2 factors had eigenvalues greater than 1 (Table 5).

Table 17: Descriptive statistics of the motivation statements

Motivation statements	Mean	Std. Deviation
To add value to education	3.68	1.261
To get training in entrepreneurship	4.06	.969
As a career	3.61	1.102
As hobby	3.98	.988
Influence from peers/friends' status	2.42	1.135
Uphold family status	2.55	1.149
For employment after school	3.43	1.268
For connections	3.64	1.103
To own business	4.03	.985
Influence from successful business	2.72	1.255
As school assignment	2.20	1.241

Table 18: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.829
Bartlett's Test of Sphericity	Approx. Chi-Square	797.832
	df	55
	Sig.	.000

Results also revealed that the total variance extracted was 55.392%. All the variables loaded significantly with no factorial complexity or mixed signals (Table 5). Communalities ranged from 0.31 to 0.65. Nevertheless, all factor loadings were above 0.4 (Table 4). Oblique rotation indicated that there was no correlation among the factors. (Table 5)

Table 19: Rotated Component Matrix and communalities

Items	Component		Communalities
	1	2	
add value to education	.823		.692
to get training on entrepreneurship	.802		.674
Career	.777		.619
Hobby	.747		.562
to own business	.741		.641
employment after school	.646		.695
Connections	.563		.461
family status		.817	.374
peers/friends' status		.800	.549
influence from successful business		.675	.511
as school assignment		.555	.316

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Results revealed that factor 1 explains 36.606% of the variance. It comprises 7 items that represent a hypothesized subscale of students participating in incubation programs with a motive that there are no better choices for work after school, and these items are; getting a career in business, adding value to education, getting entrepreneurship training, getting own business, stable employment after school, get connections and business as hobby. These constructs suggest that university students' motivation to participate in university incubation

programs is associated with a push factor of a need for employment after school (necessity motivation). That is to say; students participate in university incubation programs because they feel that their education is not enough to secure them a proper career and employment after their school. This is a highly reliable factor with an Alpha = 0.823 (Table 4).

Table 20: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.027	36.606	36.606	4.027	36.606	36.606	3.856	35.050	35.050
2	2.066	18.786	55.392	2.066	18.786	55.392	2.238	20.342	55.392
3	.923	8.392	63.784						
4	.753	6.842	70.627						
5	.682	6.198	76.825						
6	.561	5.099	81.924						
7	.530	4.822	86.745						
8	.436	3.960	90.705						
9	.410	3.730	94.435						
10	.336	3.050	97.485						
11	.277	2.515	100.000						

Extraction Method: Principal Component Analysis.

Source: Author's survey 2023

Factor 2 accounts for 18.786% of the variance. It comprises 4 items related to students participating in incubation programs with the motive of taking advantage of incubation programs as business opportunities. These items include the opportunity to fit into family status, the opportunity to get recognition from peers and friends, the opportunity to join a successful line of business after seeing successful people in it, and the opportunity to complete school assignments, which are not different from the description stated by Giacomin *et al*, (2007) who distinguish between three pull motivations: market opportunity, social status, and profit. These constructs suggest that university students' motivation to participate in incubation programs is associated with a pull factor of taking advantage of an opportunity (opportunity motivation). This shows that some students participate in university incubation programs because they want to upgrade their social status. This is highly supported by an Alpha= 0.817 (Table 4).

PLS-SEM model

Structural Equation Modelling (SEM) under Partial least square methods (PLS) (PLS-SEM model) was used to determine the factors influencing the sustainability of university-incubated agribusinesses. The structural model ascertains the significance of the hypothesized relationships between necessity motivation, opportunity motivation, personality/ behavioural, and stigma failure factors on university agribusinesses' economic, environmental, and social sustainability. First, the validity and reliability of the measurement model were assessed, and the structural model was validated.

Measurement model

Smart PLS 4.0 by Ringle *et al*. (2022) was used to assess the measurement and structural models. The assessment of the measurement model starts with evaluating the factor loadings and then establishing the construct's reliability and validity.

Factor loadings

Factor loadings determine how each item correlates with a given construct. They indicate how much an item weighs on each construct. The factor loadings and item results derived from factor analysis are illustrated below;

Table 21: The loading of items on the outer model

Items	Outer loadings
Autonomy <- behavioural factors	0.768
Democracy <- social sustainability	0.712
Engage community <- social sustainability	0.747
Innovativeness <- behavioural factors	0.800
N_career <- comp 1; necessity	0.800
N_employment_sch <- comp 1; necessity	0.637*
N_valueeduc <- comp 1; necessity	0.836
Natural_resources <- environmental sustainability	0.762
O_familystatus <- comp 2; opportunity	0.864
O_influsuccessful <- comp 2; opportunity	0.806
O_ownbusiness <- comp 1; necessity	0.777
O_peersfriends <- comp 2; opportunity	0.750
O_trainingentre <- comp 1; necessity	0.794
Optimism <- behavioural factors	0.760
Proactiveness <- behavioural factors	0.761
Risk-taking <- behavioural factors	0.719
Stigma failure <- Stigma failure	1.000
Wastes <- environmental sustainability	0.593*
Climate_change <- environmental sustainability	0.704
Discrimination <- social sustainability	0.796
Employees <- social sustainability	0.623*
Hobby <- comp 1; necessity	0.735
Interdependence <- environmental sustainability	0.765
Internal_conflicts <- social sustainability	0.706
Locus_control <- behavioural factors	0.798
Marketing_strategies <- economic sustainability	0.740
Modern_tech <- economic sustainability	0.755
Paying customers <- economic sustainability	0.707
Productivity_improve <- economic sustainability	0.761
Profits <- economic sustainability	0.663*
Relationships_trust <- social sustainability	0.719
Self_efficacy <- behavioural factors	0.799
Social_norms <- social sustainability 0.702	0.702
Pdt_plans <- environmental sustainability	0.784

Items with lower loadings are marked with (*)

Note that some of the items in Table 6 above marked with* do not have loadings above 0.7 as the preferred level indicating sufficient loading according to Hair et al. (2014) and Hair et al. (2010) (Standardized loadings should be above 0.50 or higher, and ideally 0.70 or higher). However, lower loadings between 0.4 and 0.7 can be used if the Composite Reliability (CR)

and Average Variance Extracted (AVE) are high enough for the corresponding items. (Hair *et al.*, 2014) (see below). If not, the item should be eliminated from the scale if not it will increase the CR and AVE. In this study, the CR and AVE were high enough for the \corresponding items and constructs were only removed if they were increasing the AVE and CR.

Reliability and validity

Results reveal Composite Reliability (CR) over 0.7 and Average Variance Extracted (AVE) higher than 0.5. Therefore, all loadings were acceptable for model estimation (Hair *et al.*, 2014)

Table 22: Construct reliability and validity

Items	**Cronbach 's alpha**	**Composite reliability (rho_a)**	**Composite reliability (rho_c)**	**Average variance extracted (AVE)**
Behavioural factors	0.887	0.891	0.912	0.597
Comp 1; necessity	0.858	0.871	0.894	0.586
Comp 2; opportunity	0.739	0.77	0.849	0.653
economic sustainability	0.778	0.789	0.848	0.527
environmental sustainability	0.771	0.782	0.846	0.525
social sustainability	0.849	0.877	0.880	0.514

Discriminant validity

Discriminant validity was assessed according to the heterotrait- monotrait ratio (HTMT). This is because HTMT has a better sensitivity to detect discriminant validity than the Farnell and Larcker criterion for interpreting the causal effect in the modelling analysis (Hamid et al., 2017). Results reveal a slightly high collinearity problem among latent variables: economic and environmental sustainability. However, the acceptable levels of discriminant validity <0.90, as suggested by Henseler et al. (2015), were achieved. Results from collinearity statistics reveal no problems of multicollinearity as the Variance Inflation Factor (VIF) value results of the structural equation modelling in this study is less than 5 and lies between 1 and 2.790, indicating no collinearity among study dimensions (Hair *et al.*, 2011). Also, results from cross-loadings all showed very low correlations between measures of unrelated constructs. Generally, the reliability and validity tests conducted on the measurement model were satisfactory, indicating that the items used to measure constructs are valid and fit to estimate structural model parameters.

Table 23 Discriminant validity- Heterotrait-monotrait ratio

	behavioural factors	comp 1; necessity	Comp 2: opportunity	economic sustainability	environmental sustainability	social sustainability
Stigma failure						
behavioural factors	0.665					
comp 1; necessity	0.45	0.587				
Comp 2; opportunity	0.03	0.112	0.27			
economic sustainability	0.406	0.599	0.515	0.116		
environmental sustainability	0.477	0.645	0.586	0.180	0.865*	
social sustainability	0.346	0.478	0.586	0.148	0.622	0.746

Component with discriminant validity close to 0.90 is marked (*)

The goodness of model fit

To ascertain a good model fit, the acceptable standards for model fit, according to Henseler *et al. (2014)*, were achieved. Standardized Root Mean Residual (SRMR), the difference between the observed correlation and the model-implied correlation matrix, should have a value less than (0.10 or 0.08) obtained at 0.074.

The structural model and PLS-SEM analysis

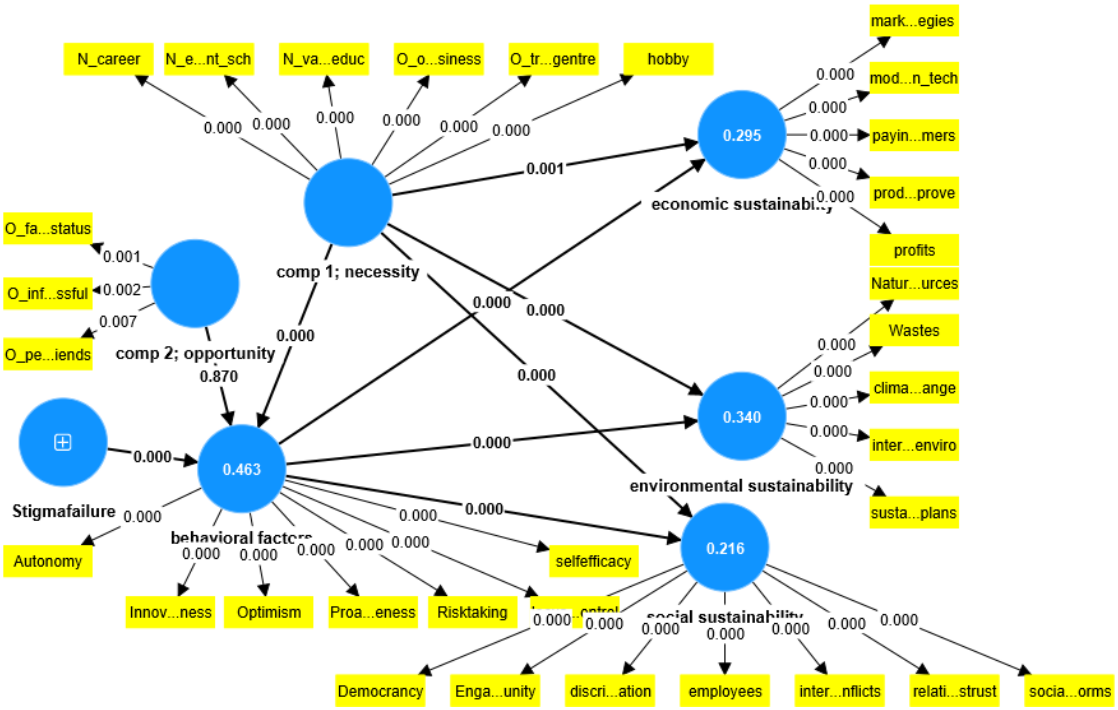

Figure 12: The structural model

The structural model indicates the path coefficients, R-squares, and outer loadings/ weights of the model.

Testing hypotheses as depicted in the structural model (Figure 1)

Direct effects

H1 evaluated whether necessity motivation (comp 1) has significant effects on the economic, environmental and social sustainability of university-incubated agribusinesses. Results revealed significant direct effects of necessity motivation on agribusinesses' economic, environmental and social sustainability at P values = 0.000, 0.000, and 0.000, respectively. These findings align with a study by Tur-Porcar et al. (2018), who based their study on intrinsic motivation as a factor affecting entrepreneurship and business sustainability. Hence, the hypothesis that there is a direct effect of necessity motivation to sustainability (H1) was supported. (Table 9)

H2 evaluated whether there are significant effects of opportunity motivation (comp 2) on the economic, environmental and social sustainability of their agribusinesses. Results revealed no significant direct effects of opportunity motivation on university-incubated agribusinesses' economic, environmental, and social sustainability (Fig 1 and Table 9). This means that opportunity motivation factors do not influence the sustainability of university-incubated agribusinesses. Therefore, the hypothesis that opportunity motivation influences university-incubated agribusinesses' economic, environmental, and social sustainability is rejected. The null hypothesis that opportunity-motivating factors do not influence the economic, environmental, and social sustainability of university-incubated agribusinesses is accepted.

H3 evaluated whether there are significant effects of behavioral/personality of students participating in university incubation programs on the economic, environmental, and social sustainability of their agribusinesses. Results revealed significant direct effects of the behavioral/personality of students participating in university incubation programs on their agribusinesses' economic, environmental, and social sustainability at P values 0.000, 0.000, and 0.000, respectively. This could be because the personality of the students in terms of innovativeness, proactiveness, and risk-taking propensity determines the use of their resources at hard. These findings are similar to findings discovered by Tur-Porcar et al. (2018) on factors affecting entrepreneurship and business sustainability on the influence of behavioral as a factor influencing entrepreneurship sustainability. (Table 9)

Table 24: Direct Relationship Results

Items	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Stigma failure -> behavioural factors	0.495	0.494	0.061	8.045	0.000
Behavioural factors -> economic sustainability	0.389	0.395	0.085	4.568	0.000
Behavioural factors -> environmental sustainability	0.387	0.392	0.065	5.961	0.000
Behavioural factors -> social sustainability	0.336	0.344	0.066	5.071	0.000
Comp 1; necessity -> behavioural factors	0.309	0.31	0.059	5.201	0.000
Comp 1; necessity -> economic sustainability	0.236	0.238	0.074	3.18	0.001
Comp 1; necessity -> environmental sustainability	0.288	0.291	0.062	4.679	0.000
Comp 1; necessity -> social sustainability	0.208	0.214	0.068	3.047	0.002
Comp 2; opportunity -> behavioural factors	0.012	0.026	0.056	0.213	0.831

Source: Author's survey 2023

Indirect effects

H1: Results in Table 10 revealed that necessity motivation factors had a significant indirect effect on agribusinesses' economic, environmental, and social sustainability. The indirect effect of comp 1, necessity through behavioural factors, affected economic sustainability. On the same note through behavioral factors, necessity motivation factors had significant indirect effects on the social and environmental sustainability of agribusinesses. Therefore, the hypothesis that there are significant direct and indirect effects of necessity motivation factors on the economic, environmental, and social sustainability of university-incubated agribusinesses is held.

H2: Results in Table 10 revealed no significant indirect effect of opportunity motivation factors (comp 2) on agribusinesses' economic, environmental, and social sustainability. These effects included comp 2; opportunity -> behavioural factors -> social sustainability, comp 2; opportunity -> behavioural factors -> economic sustainability, and comp 2; opportunity -> behavioural factors -> environmental sustainability. Therefore, the hypothesis that opportunity motivation influences university-incubated agribusinesses' economic, environmental and social sustainability is rejected. The null hypothesis that opportunity-motivating factors do not influence the economic, environmental and social sustainability of university-incubated agribusinesses is accepted.

H3: In Table 10, through behavioral effects, stigma failure has significant indirect effects on the social, economic and environmental sustainability of university-incubated agribusinesses. However, this study did not expound on how stigma failure influences the economic,

environmental, and social sustainability of university-incubated agribusinesses, as did in the study by Simmons *et al*. (2014). Results revealed in this study still confirm the significant effects of stigma failure on SMEs' economic, environmental and social sustainability. This means that the behavior and perception that people who started their businesses and have failed should start again has a significant effect on the sustainability of their businesses. Therefore, the hypothesis that there are significant effects of behavioral/personality of students participating in university incubation programs on the economic, environmental and social sustainability of their agribusinesses is accepted.

Table 25: Specific indirect effects

Paths	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
comp 1; necessity -> behavioural factors -> economic sustainability	0.12	0.124	0.041	2.969	0.003
Stigma failure -> behavioural factors -> economic sustainability	0.193	0.194	0.044	4.398	0.000
comp 1; necessity -> behavioural factors -> social sustainability	0.104	0.107	0.032	3.281	0.001
Stigma failure -> behavioural factors -> environmental sustainability	0.192	0.193	0.038	5.000	0.000
comp 2; opportunity -> behavioural factors -> social sustainability	0.004	0.009	0.020	0.204	0.838
comp 2; opportunity -> behavioural factors -> economic sustainability	0.005	0.011	0.022	0.206	0.837
comp 1; necessity -> behavioural factors -> environmental sustainability	0.12	0.122	0.034	3.539	0.000
Stigma failure -> behavioural factors -> social sustainability	0.166	0.17	0.038	4.372	0.000
comp 2; opportunity -> behavioural factors -> environmental sustainability	0.005	0.01	0.022	0.208	0.835

Conclusions

The PCA results demonstrate a clear distinction between necessity motivation and opportunity motivation of university students participating in university incubation programs. A lack of correlation between the subscales indicated that one can differentiate between the necessity and opportunity motivation of students' participation in university incubation programs. Van der Zwan *et al,* (2016) found that more individuals take the initiative to start a new venture because they see an opportunity rather than a need. However, the study in this article portrays that more university students take the initiative to participate in university business incubators because they see a need rather than an opportunity. Other factors, such as acquiring wealth, despite

being stated as the main factors for entrepreneurs to start a business (Shi & Wang, 2021) in this study, were not significant to either be in necessity or opportunity motivation. Hobby as a motivation factor, also identified by (Giacomin et al., 2007), relied more on necessity motivation than on opportunity motivation. This rejects the assumption that hobby as a motivation factor happens when neither necessity motivation nor opportunity motivation is at play. The Identified factors influencing the sustainability of university-incubated agribusinesses in Kenya include the personality of youths that participate in incubation programs, stigma failure, and the necessary motivation factors. These factors, directly and indirectly, affect each other as they influence the sustainability of university-incubated agribusinesses. Lastly, opportunity motivation factors do not influence the sustainability of university-incubated agribusinesses.

Recommendations

As youths with university-incubated agribusinesses intensify their economic, social and environmental practices and strategies to make their agribusinesses sustainable, they should also consider improving their personality as it could be a major factor influencing their agribusinesses. This may ensure the holistic sustainability of their agribusinesses. On the other hand, in university business incubators, irrespective of the motive for a student to participate in the incubation program, all students should be given a chance to participate equally in the business incubation program because neither the reason for joining nor the motive of joining determines the sustainability performance of their agribusinesses. However, the point should be that students who participate in university incubation participate because they need a better career after school. On the same note, University business incubators, despite being personal staff projects, universities with such projects should consider institutionalising university incubation projects within their policies for efficient operation. This will give room for many students to learn about the opportunity for business incubation in their school. As well as extending the sustainability of these programs. This is because an incubator's sustainability influences the business's sustainability since they are the initial mentors to the created agribusinesses through their programs.

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SUB-THEME 3

Trends in Science, Technology, Engineering and Mathematics

Advances in Science, Technology, Engineering and Mathematics (STEM) are essential pillars and drivers to innovative solutions that are vital to counter challenges due to increased societal needs. The Government of Kenya has an established policy and programme on integration of STEM from early childhood development through to graduate education. Trends in STEM are also major drivers to the advancements in ICT and the 4th industrial revolution that is expected to alter living and working environments. Knowledge, advancement and application of STEM is vital in the development of more effective tools, toolkits, techniques and technologies, for design, development and management of infrastructure, environment, agriculture, ICT and industrial processes, with optimal consideration to resources, society, technical factors and time. Abstracts, papers and posters presented under this sub-theme should address how trends in STEM can be utilized to drive solutions and innovations that address Kenya's identified priorities and other needs for sustainable development**.**

Water Quality Assessment of Tap And Kiosks Supply Systems in Lodwar Town in Turkana County, Kenya

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Abstract

Growing urban areas in developing countries face water access challenges from inadequate urban water supply systems against growing water demand. Water utilities like in Lodwar establish kiosks supplies to fill water supply gaps especially in peri-urban areas and informal settlements. However, the quality of many urban water supply systems is uncertain due to several factors that need to be established. This study assessed selected physical-chemical parameters and biological (faecal coliform densities) in water across piped and kiosks supply chains from the source to consumers in Lodwar town. Electrical Conductivity (EC), pH, temperature, and Total Dissolved Solids (TDS) were determined by universal meters Model HACH HQ 40d; HACH HQ 30d for Dissolved Oxygen (DO) and HACH HQ 11d for turbidity. Nitrate-Nitrogen (NO_3-N), was determined by calorimetric method using light spectrophotometer (420nm wavelength). Free Residual Chlorine (FRC) was analysed using Pool tester with standard colour scales for different FRC concentrations. Faecal coliforms were determined by Membrane Filtration Technique (MFT) using Oxfam - DelAqua water testing kit. Temperature (28.51-32.46°C), DO (3.78-7.50mg/L) and pH (7.58-8.38) were significantly different ($p<0.05$) across all supply chains while, faecal coliforms (6.40-340.79CFUs/100mL) were significantly different ($p<0.05$) across piped water supply chain using one-way ANOVA test (F value = 7.693; df=4, 80; p=0.000). Nitrate (0.052-0.068mg/L) was significantly different ($p<0.05$) across kiosks supply chain using one-way ANOVA test (F value = 4.195; df=3, 18; p=0.020). The faecal coliforms in all supply chains recorded higher values than WHO standards (0 CFUs/100mL) for drinking water hence showing that the water was contaminated. Inadequate water treatment, poor hygiene, improper water handling, lack of water quality monitoring and poor maintenance of piped system influenced water quality in Lodwar town. Faecal coliforms increased across all supply chains hence grossly contaminated and posing waterborne health risks to consumers. Regular water quality monitoring and treatment at the source and storage tanks are required to improve its quality.

Key words: faecal coliform, monitoring, supply chain, water quality

Introduction

Globally, by 2022, 2.2 billion people still lacked safely managed drinking water; including 1.5 billion with basic services, 292 million with limited services, 296 million with unimproved and 115 million drinking surface water (WHO and UNICEF, 2023). However, since 2015, coverage of safely managed drinking water has increased from 69% to 73%; rising from 56% to 62% in rural areas and from 80% to 81% in urban areas according to joint monitoring report by WHO and UNICEF (2023). Further, the report indicates that water quality was the most common limiting factor for safely managed drinking water services, a concern that motivated this study in Lodwar town. It is reported that if there are no interventions for improvement of water quality management by 2030, only 81% of world's population will have access to safe drinking

water at home, leaving 1.6 billion people without access to safe water (WHO/UNICEF, 2021). Many countries were reported to lose productivity to water and sanitation related diseases spending up to 5% of their Gross Domestic Product (GDP) (WHO, 2012). Additionally, economic losses were attributed to time wasted when fetching water from distant areas. Further, UNICEF in 2021 reported that 700 children under the age of five die every day from diarrhoeal diseases due to unsafe drinking water or poor sanitation and hygiene (UNICEF, 2021).

There exist formal (piped) and informal systems (vendors like kiosks) in water service provision in most urban centres especially in developing countries. In Lodwar town, these systems are managed by Lodwar Water and Sanitation Company (LOWASCO). The informal systems of water supply exist to provide water to households not served by LOWASCO or have intermittent utility water supply. This may be due to infrastructural challenges or finite water resources as suggested by other researchers (Awere and Anornu, 2016; Garrick *et al*., 2019). Delivery of safe and sustainable water supplies presents a fundamental challenge for the urbanizing world. With the increasing populations in urban areas due to rural - urban migration, piped water systems are struggling to keep pace. This has resulted to languishing of formal systems compared to informal water systems which have thrived due to high demand for water supply (Garrick *et al*., 2019). The cost to supply water to the estimated 10 billion people globally by 2050 was projected to be $60 trillion (Larsen *et al*., 2016). This would prove to be unachievable for the struggling developing countries due to the investment cost required hence giving evidence that informal water vendors would continue to play a key role in water service provision.
In Kenya, 45% of the population has no access to piped water within easy reach (WASREB, 2019), thus creating a conducive environment for water vendors to bridge the gap. Water availability and supply in many towns in Kenya is unreliable, mainly because of extensive rationing by the utility companies that arise from high demands and water shortages making human right to water untenable (UNDP, 2011). Notably, vending in some circumstances may prove to be an appropriate technology for communities at a given level of economic and social development. This is because it is typically more reliable means of water provision. According to UNDP (2011) report on small scale water providers in Kenya, fixed point water suppliers such as public taps and water kiosks are safer and more affordable compared to mobile water vendors (pushcarts and tankers).

Lodwar town was the best candidate for this study due to inadequate water access, water scarcity and stress associated to arid and semi-arid lands (ASAL) climatic conditions within the Sahel region. The water coverage in Lodwar town is at 59% (acceptable coverage is 80% and above) according to WASREB (2020) with water quality approval of 66% (a composite of free residential chlorine and bacteriological standards) against a recommended approval of not less than 90% (WASREB, 2020). Given the fact that both the water coverage and water quality approvals is below the recommended rates, there exists a water supply gap. That notwithstanding, the quality of water supplied to residents of Lodwar town is of concern as the existing water supply gap creates an opportunity for water vending to thrive. This poses waterborne disease risks like cholera, typhoid, and dysentery to households living in Lodwar town as previously reported in the area as a result of compromised water quality (WHO, 2008; IFRC, 2020). It is against this outstanding gap that this study seeks to assess physical – chemical and bacteriological quality of water supply systems in Lodwar town focusing on piped water and kiosks supply chains.

Materials and Methods

Study area

This study was conducted in Lodwar town in Turkana County, Kenya. Lodwar is located 35.62°E and 3.14°N (Figure 13) at an altitude of 477 metres above sea level (Olango, 2019). The temperature in Turkana ranges from 20 to 41°C with an average of 30.5°C (Turkana County CIDP, 2018). The mean annual rainfall received in the area is 217 mm (Opiyo *et al*., 2014; Olango, 2019) with prolonged dry periods in January, February and September.

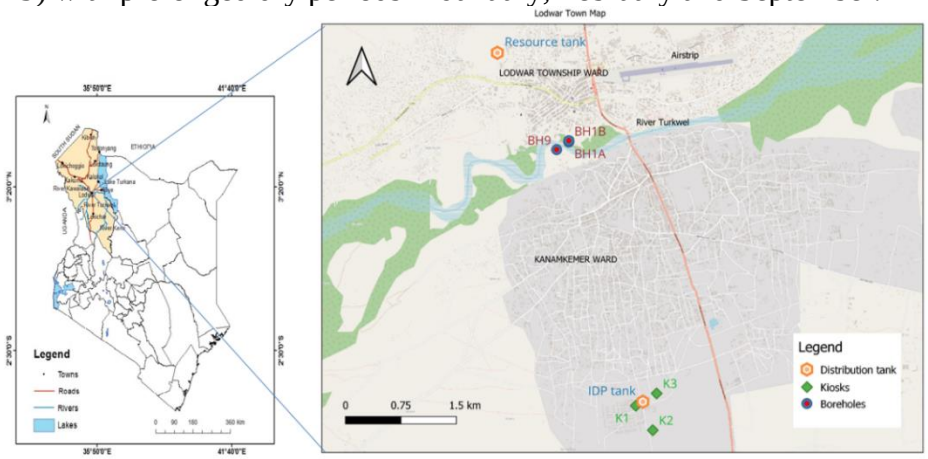

Figure 13: A map of Lodwar town showing geographical position of water sources

Source: Redrawn by the Author; Base map adapted from OpenStreetMap and contributors, CC-BY-SA

Sampling points

Selected physical-chemical and bacteriological water quality parameters across piped water and kiosks supply chains were assessed at different days within a period of 7 weeks between May and July 2021. Water samples for analyses were collected at different sampling sites (Figure 14). BH9, BH1A and BH1B are water sources (boreholes).

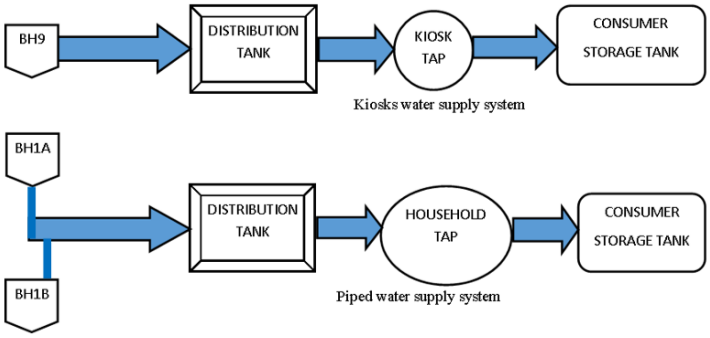

Figure 14: A flow diagram showing sampling points along supply chains in Lodwar town

A total of 72 samples for physical-chemical and bacteriological characteristics analyses were collected across the supply chains with two replicates each totalling to 144 samples (**Table 26**). All the samples were analysed in triplicates.

Table 26: Number of samples collected across water supply chains in Lodwar town

Kiosks supply chain sampling points	**Number of samples analysed for physical - chemical and bacteriological parameters**	**Piped water supply chain sampling points**	**Number of samples analysed for physical - chemical and bacteriological parameters**
Borehole 9	4	Borehole 1A	5
		Borehole 1B	5
Distribution tank	4	Distribution tank	5
Kiosks	7	Taps	22
Consumer households	7	Consumer households	13
Total	**22x2 = 44 replicates**	Total	**50x2 = 100 replicates**

Water sample collection and sampling procedures

Prior to sampling, all glassware and sampling bottles intended for physical-chemical parameter analyses were thoroughly pre-washed with acid water and then rinsed with distilled water before use for water samples collection. In addition, for microbiological analyses, during sampling; the outlet taps for boreholes and kiosks were wiped with a 70% alcohol-soaked tissue paper, and a significant amount of water flushed out before sample collection to avoid contamination as was suggested by Awere and Anornu (2016). Water samples were collected using 1000 mL plastic bottles for chemical analysis and 500 mL for microbial analysis. For sampling points without outlet taps, the samples were collected using a pre-cleaned bucket/jug then transferred to plastic bottles. Samples for *in-situ* measurements (Temperature, pH, EC, DO, TDS and Turbidity) along the supply chain were collected in a small bucket thoroughly pre-washed and rinsed with the sample to minimize interference of the parameters. The readings were taken in triplicates from the field using respective Hach Multimeters (HACH HQ 40d for EC, pH, temperature and TDS; HACH HQ 30d for DO, and HACH HQ 11d for turbidity) calibrated prior to avoid errors as recommended in the manufacturer's instructions.
The samples were preserved in cool boxes in the field and transported to Turkana University laboratory where bacteriological tests were done within 24 hours after collection. Samples for chemical analysis were kept in the refrigerator at 4°C until analyses at Egerton University water quality laboratory. FRC was analyzed *in-situ* using pool tester available in the DelAqua water testing kit by dropping one DPD (N, N-diethyl-p-phenylenediamine) No. 1 tablet at the right-hand cell (C12) of the pool tester. The sample was shaken until the tablet dissolved in the sample which were then compared through matching the colour with the pool tester standard colours representing difference residual chlorine concentrations. Nitrate - Nitrogen (NO_3-N) was analysed using Sodium-salicylate method at Egerton University water quality laboratory. All these parameters were analysed using standard methods according to APHA (2005).

Bacteriological tests to determine faecal coliform densities in water samples was done through Membrane Filtration Technique (MFT) using Oxfam-DelAqua water testing kit manufacturer's manual (Oxfam-Delagua, 2012). An aliquot of 100mL of the water sample was filtered through a sterile membrane filter paper (GFC, 47mm Ø, pour size, 0.45µm) held on a membrane filtration unit. The membrane filter paper with the bacteria retained was placed on an absorbent pad right side up on a petri-dish soaked in approximately 2.5mL of Lauryl sulphate broth, a growth medium that feeds coliform bacteria and inhibits the growth of other bacteria in the filter. The filter was incubated at 44^{o}C to allow the growth of thermotolerant faecal coliform bacteria colonies for 18-24 hours. The faecal coliforms bacteria were identified by their ability

to produce a colour change (from Red to Yellow) in Lauryl sulphate broth culture medium at 44^{o}C. The yellow colonies were counted with the help of a hand magnifying lens available in the DelAqua Kit and colonies numbers expressed as colony forming units per 100mL (CFU/100mL). This procedure is differential and selective for *E. coli* and according to the standard manual doesn't require further identification.

The data was processed using Microsoft Excel and Statistical Packages for Social Sciences (SPSS) for analysis at a significance level of 0.05. One-Way ANOVA test was used to test for the relationships in the water quality parameters across the supply chain. FRC across piped water supply chain was analysed using Independent-Samples Kruskal-Wallis test at 0.05 significance level. Subsequently, multiple means comparisons across the supply chains using Tukey HSD tests were performed to show mean differences among the sampling.

Results

Across piped water supply chain, temperature (df=4, 45; f=6.613; p=0.000), dissolved oxygen (df=4, 45; f=32.068; p=0.000), pH (df=4, 45; f=5.101; p=0.002) and faecal coliform densities (df=4, 80; f=7.693; p=0.000) were significantly different using ANOVA test ($p<0.05$). see Table 27 below. All the parameters recorded highest values at the consumers storage facilities except for temperature which highest values were recorded at the taps, with the boreholes recording lowest values.

Temperature (df=3, 18; f=3.879; p=0.027), dissolved oxygen (df=3, 17; f=6.052; p=0.005), pH (df=3, 18; f=3.674; p=0.032) and nitrate (df=3, 18; f=4.195; p=0.020) were significantly different across kiosks supply chain using ANOVA test as shown in **Table 30.** As well, the highest values for all parameters were recorded at the consumers except for nitrate which highest value were recorded at the kiosks level.

Across both piped and kiosks water supply chains, temperature, dissolved oxygen and pH varied significantly. Further, the highest values for all these parameters were recorded at the consumers and lowest values recorded at the boreholes, giving an implication that the water quality degraded from the source towards the consumer households.

Table 27: Summarized results and analysis across piped water supply chain in Lodwar town

Note: Values are presented as mean ± Standard Deviation (SD), n =46 (1-8); n =81 (9).

	Parameter	BH1A Mean ±SD	BH1B Mean ±SD	Distribution tank Mean ±SD	Tap Mean ±SD	Consumer Mean ±SD	df	F value	P value
1	Temperature (°C)	28.51±0.23 [a]	31.65±2.90 [bcd]	30.73±0.23 [acd]	31.99±1.35 [bcd]	30.95±1.20 [bcd]	4, 45	6.613	**0.000**
2	Turbidity (NTU)	2.91±3.04 [a]	1.85±0.73 [a]	2.71±3.61 [a]	2.37±2.42 [a]	3.21±3.46 [a]	4, 45	0.292	0.881
3	DO (mg/L)	5.20±0.59 [a]	3.78±0.90 [b]	6.58±0.29 [c]	7.16±0.86 [d]	7.50±0.48 [e]	4, 45	32.068	**0.000**
4	EC (µS/cm)	266.47±6.88 [a]	272.13±5.94 [a]	266.73±5.86 [a]	268.92±7.84 [a]	268.77±9.38 [a]	4, 45	0.417	0.796
5	TDS (mg/L)	51.00±1.18 [a]	52.35±0.91 [a]	51.75±1.46 [a]	51.96±1.32 [a]	51.85±2.82 [a]	4, 45	0.394	0.812
6	pH (range)	7.72-8.06 [ac]	7.63-7.94 [ab]	7.68-8.07 [ab]	7.70-8.29 [abc]	7.93-8.38 [c]	4, 45	5.101	**0.002**
7	FRC (mg/L)	0 [a]	0 [a]	0 [a]	0.07±0.28 [a]	0 [a]	4, 45	0.441	0.779
8	Nitrate (mg/L)	0.068±0.012	0.057±0.004	0.065±0.004	0.066±0.006	0.067±0.01	4, 45	1.832	0.139
9	Faecal Coliforms (0 CFUs/100mL)	34.70±82.73 [a]	13.90±39.52 [a]	11.50±10.74 [a]	31.55±74.95 [a]	151.04±144.74 [b]	4, 80	7.693	**0.000**

Superscript letters across the rows represents post hoc test analysis.
Different superscript letters in a row are significantly different while same superscripts are not significant, p< 0.05 using Tukey HSD test.
Bolded values: indicate significantly different p-values.
P-values are based on one-way ANOVA test at 0.05 significance level except for FRC that based on Independent-Samples Kruskal-Wallis test.

Table 28: *Summarized results and analysis across water kiosks supply chain in Lodwar town*

Note: Values are presented as mean ± Standard Deviation (SD), n =19 (1-2,4-6, 8); n =21 (9).

	Parameter	BH9 Mean ±SD	Distribution tank Mean ±SD	Kiosk Mean ±SD	Consumer Mean ±SD	df	F value	P value
1	Temperature (°C)	28.61±0.32[a]	32.34±2.06[ab]	31.88±0.60[ab]	32.46±2.95[b]	3, 18	3.879	**0.027**
2	Turbidity (NTU)	4.09±2.32 [a]	4.08±2.50 [a]	3.05±1.99 [a]	5.74±2.06 [a]	3, 18	1.841	0.176
3	DO (mg/L)	4.48±0.87[a]	5.72±1.31[ab]	5.44±0.69[ab]	6.57±0.62[b]	3, 17	6.052	**0.005**
4	EC (µS/cm)	301.67±3.74	303.58±3.30	304.43±3.21 [a]	307.05±7.63 [a]	3, 18	0.996	0.417
5	TDS (mg/L)	57.42±4.07 [a]	57.83±1.82 [a]	58.59±1.85 [a]	55.89±5.19 [a]	3, 18	0.657	0.589
6	pH (range)	7.58-7.95 [a]	7.81-8.07 [a]	7.63-7.95 [a]	7.82-8.14 [a]	3, 18	3.674	**0.032**
7	FRC (mg/L)	0 [a]	0 [a]	0 [a]	0 [a]	-	-	-
8	Nitrate (mg/L)	0.052±0.001[a]	0.052±0.002[ab]	0.056±0.002[b]	0.054±0.002[ab]	3, 18	4.195	**0.020**
9	Faecal Coliforms (0 CFUs/100mL)	88.10±127.38 [a]	185.10±303.96 [a]	284.79±312.99[a]	340.79±199.49 [a]	3, 20	1.14	0.357

Superscript letters across the rows represents post hoc test analysis.

Different superscript letters in a row are significantly different while same superscripts are not significant, p< 0.05 using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-values are based on one-way ANOVA test at 0.05 significance level except for FRC that based on Independent-Samples Kruskal-Wallis test.

Discussion

Physical-chemical characteristics of water across water supply chains

Across all water supply chains, temperature varied significantly from the source to the consumers indicating that various factors influenced water temperature. The temperature across piped water system increased from boreholes to the taps with a slight decrease at the consumers' point of use. On the other hand, temperature across kiosks supply chain increased at the consumers' level. The change in temperature across the supply chains was influenced by the time of sampling, ambient temperature of the surroundings and nature of storage tank material as suggested by Hoko (2008) in Bindura District, Zimbabwe and in a review by Salehi (2022). As the water was being piped to households and kiosks, storage tanks and pipes were exposed to the sun hence hot temperatures influencing water temperature. At the taps consumers, the temperature of water decreased as the water was mostly stored in containers under shades or inside the houses. Slavik *et al*. (2020) noted that shading reduces storage tanks exposure to direct sunlight hence reducing potential for microbial growth. Increased temperature in water storage tanks was reported in other studies to increase microbial growth in water (Salehi, 2022). Contrary, increased water temperature was recorded at the kiosks consumers attributed to storage options at the households' level which may have exposed storage containers to sun radiations as most of them were internally displaced persons (IDPs) with inadequate established households' structures. Peter and Routledge (2018) observed that higher temperatures favoured microbial growth and biofilm formation in water storage facilities in London, UK agreeing with the findings of this study as faecal coliforms and temperature increased from the source to consumers. Notably, temperature at the kiosks distribution tank was slightly higher compared to the kiosks and the source. This was attributed to the fact that the distribution tank was exposed to sun radiations and therefore was heated, influencing the temperature of water it stores and growth of contaminating microbes similar to findings of other researchers (Hoko, 2008; Salehi, 2022). Further, high temperature was reported to affect chemical reactions in water hence influencing other water quality parameters in Osun state, Nigeria (Olajire and Imeokparia, 2001).

Turbidity levels slightly varied across all supply chains with values obtained at all sampling points complying with WHO recommended value of below 5 NTU for drinking water except at the kiosks consumers level which recorded higher value (WHO, 2017). This was an indication that tap water was safe for use compared to kiosks water similar to the findings of Chalchisa *et al*. (2017) in storage tanks in Jimma town, Ethiopia. Nevertheless, the slightly high turbidity values recorded at the kiosks consumers could be attributed to the presence of particulate matter such as dust and pollen grains as reported in Logone Valley, Chad-Cameroon (Sorlini *et al*., 2013) or hygiene conditions of storage facilities at the households reported in Cochabamba, Bolivia (Schafer, 2010). Moreover, a study by Kothari *et al*. (2021) in Uttarakhand, India underpinned that the turbidity levels in water occurred due to the presence of soil, organic and inorganic matter, plankton, and other microscopic organisms, assertions that could apply to this study. As water was used, storage containers were constantly agitated allowing resuspension of particles in water hence increased turbidity similar to the findings of Hoko (2008) in Bindura district, Zimbabwe. The decreased turbidity at the kiosks could be attributed to sedimentation at the distribution tank although its variance across the supply chain was not significant. The higher turbidity levels recorded at the

kiosks consumers (5.74±2.06 NTU) were above WHO recommended levels of 5 NTU for drinking water (WHO, 2017). This was an indication that the water was not desirable for drinking purposes, pointing to the need for households' treatment before consumption.

Electrical conductivity recorded relatively varied values across piped water and kiosks supply chains but were not significantly different. This infers that there were very little dissolved solids like carbonates and bicarbonates added to the water across the supply chains which could have caused ionization of the water to influence the EC just as it was noted in Wondo genet campus, Ethiopia (Meride and Ayenew, 2016).The EC values decreased at the piped system distribution tank with a slight increase at the taps and the consumers compared to high value at borehole 1B. This trend could be attributed to the fact that water from the two boreholes filled the same distribution tank which may have neutralize the two boreholes' EC values, as it was also reported by Salehi (2022) that blending water from different sources could alter its water chemistry. Nevertheless, the relatively high EC values at borehole 1B could be due to increased TDS and temperature at the borehole pointing to presence of dissolved ions like carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and organic ions in water just as was reported by Lukubye and Andama (2017) in some water sources in Mbarara municipality, Uganda. On the other hand, the increased EC concentrations across kiosks supply chain may be an indication of presence of dissolved substances in water as noted above and observed in the increasing trend of TDS from the source to the consumers. However, increased EC values at the consumer households compared to other samplings sites may be due to presence of dissolved ions due to poor handling or improper storage as observed in Bindura District, Zimbabwe by Hoko (2008). The EC values recorded across the supply chains were below WHO acceptable guideline of 400 µS/cm for drinking water suggesting the water was safe for domestic use (WHO, 2017). This assertion was contrary to the findings of Rusiniak *et al*. (2021) who found some boreholes water in Turkana exceeding WHO acceptable EC guidelines of 400 µS/cm.

Dissolved oxygen concentrations varied significantly across all the water supply chains suggesting that DO was significantly influenced by several factors between the source and consumers. The boreholes recorded lowest DO values attributed to the fact the underground water are low in DO and factors such as depth of the borehole, groundwater temperatures and oxidation - reduction potential influenced its concentrations as similarly reported by Zan *et al*. (2019) in Hong Kong, China. Depletion of dissolved oxygen in water supplies was reported to encourage microbial reduction of nitrate to nitrite and sulfate to sulphide, and could cause an increase in the concentration of ferrous iron, with subsequent discoloration at the tap when the water is aerated (WHO, 2017). This assertion could agree with the results of this study as nitrate concentrations were low at the boreholes just as was the concentrations of DO. The increased concentration of DO across piped water supply chain and highest at the consumers, was contrary to the findings of other researchers that a decrease in DO is expected when the temperature increases as observed by Lukubye and Andama (2017) in Mbarara Municipality, Uganda. Wang *et al*. (2022) further suggested that DO is expected to decrease with high retention time of water in the pipeline. Therefore, the increase of DO concentrations across the supply chain could be attributed to re-aeration at the sampling points (distribution tank, tap and consumer storage tanks) hence explaining why DO levels were high at the consumer level. The decrease in DO at the kiosks level can be due to water piping from the distribution tank to kiosks as was suggested by Wang *et al*. (2022) that long hydraulic retention time of water in the pipes could cause a decrease in DO concentrations, potentially deteriorating water quality. DO concentration in water was reported to

be influenced by the source, water temperature, treatment and chemical or biological processes taking place in the distribution system (WHO, 2017). These factors may be responsible for the DO variance across the supply chains in Lodwar town including increased levels at the consumers attributed to aeration during storage.

The water pH varied significantly across all water supply chains, attributed to handling and storage at various sampling sites similar to observations of Meride and Ayenew (2016) in Wondo genet campus, Ethiopia. Further, several factors have been reported to influence pH of water including; water sources, water storage tanks or vessel materials, temperature, mineral absorption, dust, the level of bacterial activity in a vessel, and duration of water storage before use (Packiyam *et al*., 2016; Manga *et al*., 2021). The water pH was considerably high at the consumers storage facilities compared to other sampling sites agreeing with findings of other studies in Al-Karak province, Jordan by Ziadat (2005) and Chalchisa *et al*. (2017) in Jimma, Ethiopia that water pH increased upon storage. As well, airborne contaminants like dust or algae when it grows in the storage facilities produces weak carbonic acid lowering the pH of water as was suggested in Bindura district, Zimbabwe by Hoko (2008). Nevertheless, the pH values recorded across the supply chains suggested that the water was alkaline as all values recorded were above the pH of 7 although within WHO acceptable values of 6.5 – 8.5 hence water was safe for drinking (WHO, 2017). In another study in Bindura district, Zimbabwe, Hoko (2008) noted that pH tend to influence taste in water and therefore could have aesthetic implications.

Free residual chlorine was only detected once at the tap level across piped water supply chain implying inadequate water treatment which could be due to chlorine dosing, residence time of water at the distribution tank and presence of dead zones in storage tanks as observed in La Sirena, Cali, Colombia by Araya and Sanchez (2018). In all other sampling sites across piped water supply chain, FRC was not detected contrary to the information given by the water utility that the water was treated twice in a week. FRC across kiosks supply chain was not detected at all sampling points, revealing that the water inadequately or was not treated before being supplied to consumers and at the household level. The findings of the study compares with results obtained by Kothari *et al*. (2021) in all water samples tested in Uttarakhand, India where chlorination was not detected hence a high risk of water contamination across the supply chain exposing consumers to waterborne disease risks.

The nitrate concentrations slightly varied across piped water supply chain but the values detected at various sampling points were not significantly different. This points out to low oxidation potential and less interaction among nitrogen derivatives in water which in the presence of favourable temperature and sufficient alkalinity enhance nitrification processes such that ammonia is oxidized to nitrite, which are again oxidized to nitrate according to Rantanen *et al*. (2018). The increased nitrate concentrations at the kiosks may be attributed to organic pollution at the distribution tank due to presence of birds droppings observed at the top of the distribution tank during field work. This was an indication that water could easily get contaminated with these organic materials. Nitrate significantly varied across kiosk supply chain, a clear indication that vendors' water handling and hygienic conditions at the sampling points had influence in the distribution of nitrate. Nevertheless, nitrate levels were within WHO permissible limit of less than 50 mg/L in drinking water across all supply chains (WHO, 2017). The result obtained in this study concur with the findings of other researchers in Bihar and Telangana, India and Wondo Genet campus, Ethiopia that nitrate were within permissible levels in drinking water (Sukumaran *et al*.,

2015; Meride and Ayenew, 2016; Adimalla and Qian, 2019). However, these findings were contrary to what was reported by other researchers in some boreholes water in Turkana that nitrate concentrations exceeded WHO permissible standards which may lead to health risks such as methaemoglobinaemia and thyroid (WHO, 2017; Rusiniak *et al*., 2021).

Faecal coliforms densities across piped water and kiosks supply chain

Across the supply chains, faecal coliforms densities increased from the borehole to consumer point of use pointing to recontamination of water at all sampling points. The boreholes recorded less faecal coliforms attributed to the fact that water sources were groundwater with less contamination compared to other exposed sampling points as was similarly suggested by Onajite *et al.* (2018) in Benin metropolis, Edo State and Boadi *et al*. (2020) in Kumasi, Ghana. Increased faecal coliform densities across the supply chains may be due to water quality degradation during households storage if not well managed, resulting to faecal contamination as reported by Opryszko *et al.* (2013) in Ghana. In respect to this study, the faecal coliforms detected at the source could be attributed to the effects of floods which destroyed boreholes, filling them with flash floods water. This was observed during field work (personal communication from LOWASCO field staff) and also reported in studies conducted in Anambra state, Nigeria and South Eastern Nigeria (Onuorah *et al.,* 2019; Nwaiwu *et al*., 2020). In such situations, flushing by pumping out flood water and disinfection using sand filtration and high-strength calcium hypochlorite (HSCH) or calcium hypochlorite as high-test hypochlorite (HTH) was suggested by Godfrey and Ball (2003) in Kuito, Angola. Obeng *et al.* (2010) in a study conducted in Cape Coast, Ghana asserted that poor management (lack of regular cleaning and disinfection) at the source could be a cause of poor quality of water supplied to customers. The findings of this study agrees with the results of other studies that observed faecal coliforms in boreholes and ground water due to factors such as human activities in Bihar, India (Sukumaran *et al*., 2015); subsurface sediments contamination during borehole drilling using air percussion drilling methods in Lyon, France (Malard *et al*., 2005); proximity of the boreholes to shallow septic tanks in Umoja Innercore estate, Nairobi (Nyakundi *et al*., 2020) and destruction by floods observed in Anambra state, Nigeria and South Eastern Nigeria (Onuorah *et al.,* 2019; Nwaiwu *et al*., 2020). Gwibi *et al.* (2019) in a study conducted in Mohale Basin, Lesotho observed a significant relationship between *E. coli* counts in water sources samples and lack of water source protection, high prevalence of open defecation, unhygienic practices, presence of livestock faeces and latrines within the proximity of water sources. These factors may probably played part in the presence of faecal coliforms at the water sources in Lodwar.

Contamination at the households level may be explained by lack of regular cleaning of storage containers or tanks, broken pipes, poor handling (e.g., use of unsanitary dips) and unhygienic conditions such as lack of hand washing after visiting toilets or before handling the water as well as inefficient treatment at the distribution tanks similar to observation of Gwibi *et al.* (2019) in Mohale Basin, Lesotho. The latter applied in this study since it was observed that there was no treatment of water at the source and treatment at the distribution tanks was not regular. The results obtained in this study are consistent to the findings of Kwami and Sawyerr (2018) in Gombe Metropolis, Nigeria that water storage facilities favoured microbial and faecal coliforms due to lack of cleaning and proper sanitation of such containers and storage facilities coupled with lack of basic households treatment of drinking water and/or low levels of FRC resulting to faecal contamination. Opryszko *et al.* (2013) in a study conducted in Ghana noted that water quality

degrades during household storage including faecal contamination which may explain increased faecal coliform densities at the households' level obtained in this study. Gizachew *et al*. (2020) affirmed that contamination of water at the consumer households may result from mishandling during storage or the storage containers may not be hygienic as was observed in their in Boloso Sore Woreda, Ethiopia. Further, water contamination at the consumers just as observed in this study was attributed to lack of/or inadequate treatment, poor hygiene conditions and contaminated storage facilities in a research conducted in Gombe Metropolis, Nigeria (Kwami and Sawyerr, 2018). Howard and Bartram (2003) observed that consumption of poor-quality water by households was a key pathway for transmission of infectious diarrhoeal diseases. The result of this study agrees with the findings of Opryszko *et al.* (2013) in rural Ghana who suggested that recontamination pathways across the supply chain may be as a result of unclean hands contact with stored water, mixing water from multiple sources, collection and storage vessels contamination, transfer of water from one container to the other, and source contamination (contamination at the borehole, kiosks or distribution tanks). According to WHO guidelines, drinking water sources are expected to be free from faecal contamination (WHO, 2017). This is contrary to the findings of this study as faecal coliforms are present in all sampling points across all supply chains an indication the water was not safe for drinking hence a waterborne health risk to the consumers. This calls for household end point of use treatment methods like chlorination, filtration, boiling or solarization to improve water quality.

Conclusion and Recommendations

Several factors including inadequate water treatment, poor hygiene, improper handling of water, lack of monitoring and regulation influenced water quality across all supply chains in Lodwar town. Faecal coliforms were recorded in all sampling points across both piped water and kiosks supply chains while turbidity at the kiosks consumers exceeded WHO standards for drinking water quality implying the water was not safe for drinking. The free residual chlorine (FRC) was detected only once at the taps along piped system while it was not completely detected across kiosks supply chain over the period of study, which poses waterborne health risks to the consumers. This was evident through faecal coliforms contamination observed in all sampling points across the supply chains hence the water was not safe for drinking unless it is treated at the households' level before use. In view of this, we recommend as follows; a) water treatment should be done at the source or distribution tanks before the water is supplied to the consumers to avoid exposure to waterborne health risks associated with water contamination, b) regular water quality monitoring should be adopted by LOWASCO in collaboration with the Public health department to ascertain quality of water supplied to the residents of Lodwar town, and c) community sensitization on water, sanitation and hygiene (WASH) should be a priority to consumers in Lodwar town so that they are able to verify water quality at households' level or treat water before use.

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SUB-THEME 5

One Health Approach, Health Systems Mangement,

Health Financing, Pandemic Preparedness and Surveillance

The health of humans, animals and ecosystems are closely interlinked and changes in these relationships can increase the risk of new human and animal diseases developing and spreading. Collaboration, communication and coordination is required between the relevant sectors. Ensuring planetary health, proper planning, directing, and coordinating medical and health services, coupled with adequate sources of financing is required to ensure proper health and pandemic control. Further, the Covid-19 pandemic highlighted the need for pandemic preparedness. In the modern interconnected world, safeguarding global health security is vital for maintaining public health for any nation. Emergency preparedness is key to controlling the emerging public health challenges at both national as well as international levels. Surveillance systems, disease modelling and forecasting play a pivotal role in both policy building, disease detection, prevention and response to potential health threats. This sub-theme calls for abstracts, papers and posters that focus on the one health approach, health system management, health financing, pandemic preparedness and surveillance.

Health Facility Barriers to Effective Management of Breast Cancer Pain at A County Referral Hospital in Kenya.

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Abstract

Background: The incidence of breast cancer has been increasing over the last two decades and is expected to continue, this is partly due to improved screening, treatment strategies and an increasing aging population. With the increasing cases of breast cancer, the proportion of patients needing pain management also increases**,** despite measures to improve cancer pain management, suboptimal cancer pain management is increasingly common among patients with breast cancer as a result of health facility barriers. The aim of this study was to assess the health facility barriers that limited effective management of breast cancer pain by nurses at a County Referral Hospital in Kenya.

Methods: This was a mixed methods study of nurses who were working in hospital departments caring for patients with breast cancer, and nurses' departmental heads and other departmental heads who were involved with pain management. Institutional Review Board approval was obtained. Quantitative data was collected using a structured self-administered questionnaire and analysed using Statistical Package for Social Sciences (SPSS) version 23. Qualitative data was collected using a Focused group discussion guide and analysed through thematic content analysis.
Results: The results showed strict controls on opioid analgesics (25.0%), prescription regulations (29.8%), fear of opioids (17.9%), unavailability of opioid analgesics (41.7%), late referrals to pain speciality and lack of periodic evaluation of pain management processes with similar themes arising from the qualitative interviews.

Conclusions and recommendations: The health facility barriers reported by the respondents and affirmed by the departmental heads limited the nurses' ability to optimally provide cancer pain management as per their scopes of practice, the researchers recommend that the Kisii County department of health adopts effective models of opioid ordering and distribution to expand the scope of accessibility to morphine and other opioids for patients with breast cancer, the county also has the potential to locally produce morphine and other opioids, employ oncology specialities and adopt highly effective models of training on cancer pain management.

Key words
breast cancer, cancer pain, heath facility barriers, nurses

INTRODUCTION

Health system barriers that limit the ability of nurses and other healthcare workers to optimally manage patients with breast cancer pain, have been described by various researchers, this include insufficient access to appropriate opioid analgesics creating barriers to cancer pain relief for patients who require aggressive pain management, this is especially more severe in developing countries leading to poor quality of life among cancer patients (Scholten et al 2017; WHO, 2020). About 43.7% of the nurses in a study done in an oncology hospital in Tirana, reported delays in getting a prescription from a physician as one of the barriers they experienced in providing timely treatment (Imeraj, Veseli, and Pirushi, 2022), a study done among patients by the American Cancer Society Cancer Action Network and the Patient Quality of Life Coalition reported challenges of accessibility to opioid analgesics due to regulatory controls imposed on opioid drug abuse (ACSCAN and PQLC, 2018) while 69.5 % of nurses in a West Bank study cited strict regulations to opioid use with 56.4% expressing frustrations with delays in obtaining a prescription of opioids for their patients due to the long processes (Toba, Samara, and Zyoud., 2019).

In a Cyprus study, barriers to opioid use reported included; inadequate training of healthcare professionals (Charalambous et al, 2019) and fear of opioids and side-effects among healthcare workers (Oliveria, 2018; Charalambous et al, 2019).

According to the 2022 report by the International Narcotic Board, only 14.3% of morphine is used by low and middle-income countries including sub-Saharan Africa, 85.7% of global consumption of morphine for pain management was utilized by countries in North America and Europe (International Narcotics Control Board, 2022) revealing disparities in worldwide opioid use for cancer pain management (WHO, 2020).

A multicentre study done in Italy to determine adequacy, effectiveness and factors affecting pain management among patients referred to radiation therapy reported inadequate pain management and late referrals of cancer patients to pain specialities; this was evident as 42.9% of patients reported pain due to inadequate analgesic therapy; 72% of patients referred for palliative radiation therapy and 75% referred for curative radiation therapy had ineffective analgesic therapy and delays with referral (Donati et al, 2024).

Odonkor, Kim and Erdek (2017) described barriers to cancer pain management in Sub-Saharan Africa which included; limited funding, inadequate healthcare infrastructure and lack of trained health professionals, limited accessibility to potent analgesic drugs has also been reported as a barrier (Odonkor, Kim and Erdek, 2017; Nchako et al, 2018). Other barriers that have been described in Sub-Saharan Africa include; over regulation and legal restrictions of opioid analgesics (Kwon, 2014; Onsongo 2020), increasing incidence of abuse of opioid analgesics and increasing illegal smuggling of opioids through Africa to Europe (Kurth et al, 2018) further worsening the regulations imposed on use of opioids this may necessitate policy reviews which will address illegal use of opioids while improving accessibility of opioids for clinical use (Magboh et al, 2023).

A parallel mixed methods study done across three countries; Mozambique, Swaziland and Zimbabwe, to identify country-specific and broader regional barriers as well as administration of opioid analgesics, identified barriers to accessing opioids for clinical use; the barriers identified included overly restrictive controlled laws, use of stigmatizing language in key documents "e.g dangerous drugs" inaccurate actual opioid consumption estimation practices, knowledge gaps in

the distribution, storage and prescription of opioids, critical shortage of prescribers; and high out of pocket financial expenditures for patients against a backdrop of high levels of poverty (Namisango et al, 2018).

The findings of a study done in Ethiopia to assess the costs of a life limiting illness found out that, in the oncology unit, among the 95.5% of the patients who reported moderate to severe pain, 24% were not prescribed opioids, additionally, the patients reported very high costs of accessing pain medications (Reid et al, 2018). Other health system challenges described by researchers included; shortages of specific staff specialties for cancer pain management, low resource allocation to cancer pain management (Namisango et al, 2018), time constraints due to shortage of nurses, inadequate training and lack of clear workplace policies on utilization of specific pain assessment tools leading to poor pain assessment and rating in cancer patients (Deldar, Froutan and Ebadi, 2018).

As of the year 2018, the Kenya Facility Assessment report showed that the mean availability of palliative care services was low with 3% of facilities offering palliative care services; availability of tracer items like morphine was 5% in facilities offering palliative care services (MOH, 2021).

MATERIALS AND METHODS

Study Design:

This was a mixed methods study utilizing both quantitative and qualitative approaches.

Study Area:

The study was carried out at the Kisii County Teaching and Referral Hospital, Keumbu Sub County Referral Hospital, Taracha Health Centre and Nyamemiso dispensary. Kisii County Teaching and Referral Hospital is a referral hospital for nine (9) Sub-Counties which had a catchment population of 41, 682 thousand people at the time of the study.

Study Population:

The study targeted all nurses working at the Kisii County Teaching and Referral Hospital and nurses and other departmental heads who were directly involved with cancer pain management.

Sample Size and Sampling:

The sample size was determined using the formula shown below for a finite population (Kothari, 2004).

$$n = \frac{(Z^2 \times p \times q \times N)}{(e^2 (N-1) + (Z^2 \times p \times q)}$$

Where: n= the desired sample size when the study population is a finite number, N= the total number of the target population, Z= the value of the standard variant at a given confidence level.

The Z-values for confidence levels are: 1.645 = 90.0% confidence level 1.96 = 95.0% confidence level 2.576 = 99.0% confidence level. For this case, the researcher used 1.96.

p= the proportion of the target population estimated to have the desired characteristics.

In this study practices on cancer related pain management was at 23.3% (previous study). Therefore *p*= .233. q=1-*p*=.767. e=error margin, the precision desired by the researcher in respect of estimates concerning the population parameters. In this study the mean of the universe is estimated within .05 of the true mean within 95.0 % confidence interval.

N=244, Z=1.96, *p*= .233, q= .767 and e= .05

$$n = \frac{(1.96^2 \times .233 \times .767 \times 244)}{(.05^2 (244-1) + (1.96^2 \times .233 \times .767)} = 129.5$$

=130 respondents

$$\frac{10}{100} \times 130 = 13$$

= 130+13 = 143 respondents.

Sampling:

Kisii teaching and Referral Hospital was purposively selected since it was involved with care of patients with breast cancer. Systematic Random sampling was used to select the sample for nurse respondents. Sampling to the FGDs was purposively done, departmental heads selected were directly involved with pain management. Those who participated in the first round of the Focused group discussions included nurses who were heading the departments of internal medicine, surgery, obstetrics and gynaecology and outpatient, the nursing officer in charge of the hospital, hospital pharmacist, Medical Officer in-charge of Continuous Medical Education (CME), Clinical Officer in-charge of Continuous Medical Education and Nurse in charge of CMEs. The second round of Focused Group Discussions involved nurses who were in-charges of medical, surgical, gynaecology, palliative clinic and outpatient, the nursing officer in charge and departmental heads of Keumbu Sub-County Referral Hospital, Taraacha Health centre and Nyamemiso dispensary.

Data Collection Instruments

A structured self-administered questionnaire was used to collect data from the nurse respondents, the questionnaire was adopted and modified from the 'Knowledge and Attitude Survey Regarding Pain The Focused Group Discussion Guide (FGD) was developed by the researcher using single items from the knowledge and attitude survey regarding pain (Ferrell and McCaffery, 2014), the WHO analgesic ladder (Anekar et al.,2023) and the Agency for Health Care Policy and Research guidelines (Fonteyn, 1998)

Data Collection Procedure:

Quantitative data was collected using a self-administered questionnaire, given to the respondents while on duty. For qualitative data, the researcher used Finch, Lewis and Turley (2003) method of focused group discussions for managing the setting; the discussions were conducted by the researcher who acted as the moderator assisted by a research assistant who took notes, the researcher welcomed and thanked the participants; an introduction session followed; the researcher then explained the purpose of the focused group discussions, participants then signed the consent forms which were randomly assigned codes to refer to them during the discussion in order to ensure anonymity and for future verification of data, the participants were then reminded that the discussion was open for honest and different viewpoints and that there were no right or wrong answers. They were requested to respect each other's opinions. The researcher (moderator) ensured that every participant in the focused group had an opportunity to speak. The focused groups then discussed topical issues related to management of breast cancer pain as per the focused group discussion guide. The discussion was tape-recorded in order to capture the verbal responses, the note taker took notes as the discussion went on while the researcher noted the main points which were later combined with the tape-recorded discussion points as retrieved verbatim. The first FDG took a total of 120 minutes while the second one took approximately 112 minutes.

Data Management and Analysis:

Quantitative data was checked, coded, and analysed using Statistical Package for Social Sciences version 23 and the results are presented in narrative form, figures and tables. The researcher applied the three methods of analysing qualitative data; coding the data, interpreting the data and reporting the data (Morgan, 1997). The discussions were recorded and securely saved in the researchers account, after data collection and transcription by RE verbatim on Microsoft word, the transcripts were analysed through thematic content analysis. the common themes, ideas and patterns were identified by tracking the frequency of occurrences, classifying, sorting and organizing the data, this later enabled the researcher to make conclusions on the final thematic categories. The results are presented in narrative form as per the theme categories.

Ethical Considerations:

Ethical approval was obtained from Kenyatta National Hospital-University of Nairobi Ethics and Review Committee (KNH-UON ERC) (P446/08/2017; Ref KNH-ERC/A/40 and KNH/ERC/R/123), a permit and research authorization were obtained from the National Council of Science, Technology and Innovation (NACOSTI/P/18/86900/22659; NACOSTI/P/24/38243) and Kisii County Department of Health (D.1/55/2018/vol.11/210). Permission to enter the wards was given by the hospital and respective ward in charges, the respondents had full disclosure of information regarding the objectives of the study, those who agreed to participate gave written consent. The data collected was treated with confidentiality.

RESULTS

A total of 97 out of sample size of 143 nurses were interviewed during the study which is a 68% response rate. The study also conducted two focused group discussions (FGDs) with the departmental heads directly involved with pain management to enable the researcher get a deeper understanding of the health system barriers affecting breast cancer pain management. The response rates were 100% (1st FDG) and 80% (2nd FDG) respectively.

Socio-demographic characteristics of participants:

Table 1: Nurses' demographic characteristics

	Age	Frequency	Percent
Age	21 - 30 years	38	41.8
	31 - 40 years	35	38.5
	41 - 50 years	11	12.1
	51 years and above	7	7.7
	Total	91	100.0
Gender	Male	34	35.4
	Female	62	64.6
	Total	96	100.0
Marital status	Married	55	56.7
	Single	29	29.9
	Widowed	7	7.2
	Separated	6	6.2
	Total	97	100.0
Highest level of nursing	KECHN	14	14.7
	KRCHN or KRN	60	63.2
	BSCN	17	17.9

education attained	MSCN	3	3.2
	PHD in Nursing	1	1.1
	Total	95	100.0

About 23.7% of the respondents had undergone additional formal training on cancer related pain management.

Nurses' perceived health facility barriers

The researcher sought to know if there were barriers created by the health facility. To answer this question, the researcher sought to know the following from the nurse respondents; what limited their ability to administer opioid analgesics as per the clinical decision making algorithms, this was a multiple response question, and on this first question, the items the respondents were to choose from included; *prescription limitations by the facility, availability and accessibility of opioid analgesics. number of healthcare professionals with specialized skills on cancer-related pain management* and availability of supportive systems in relation to breast cancer pain management which were*; timely referrals to healthcare professionals with specialized skills, a quality improvement interdisciplinary team for cancer pain management and availability of ongoing education, supervision, and support for nurses and other health professionals who were directly involved in breast cancer pain management.*

Limitations to administration of opioid analgesics.

The respondents in this study were asked to state what limited their ability to administer opioid analgesics, the results are as shown in figure 1.

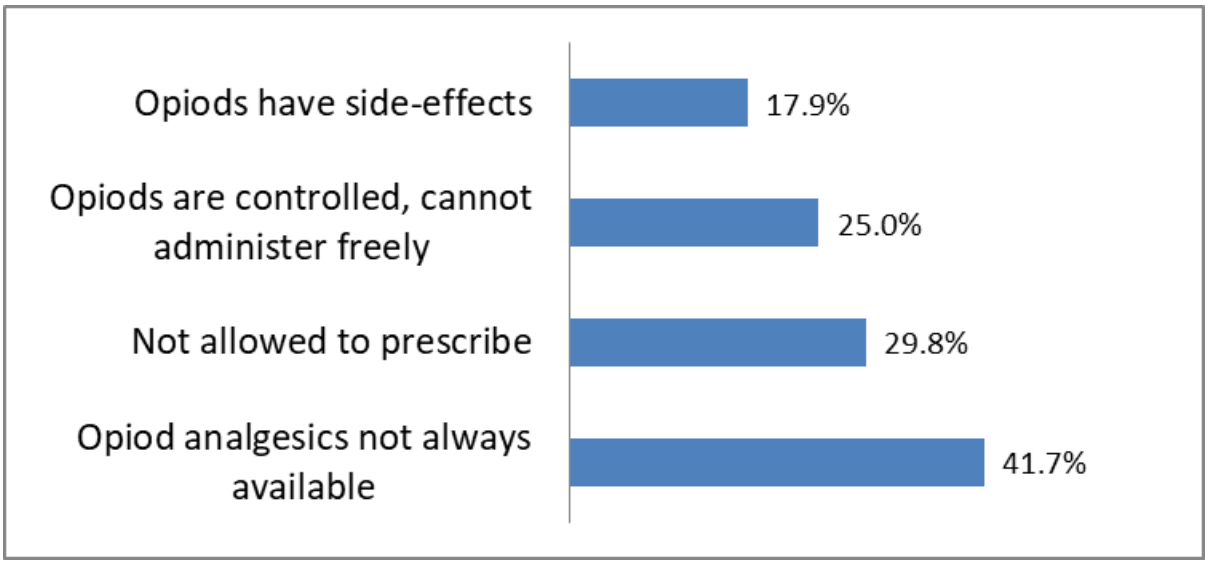

Figure 1: *Limitations to administration of opioid analgesics* (n=96)

The respondents reported that opioid analgesics were controlled and could not be administered freely (25.0%), not allowed to prescribe (29.8%), opioids have side effects (17.9%) and opioid analgesics were not always available (41.7%)

Number of healthcare workers with specialized skills

The respondents were asked to state the number of healthcare workers with specialized skills on cancer pain management and about 18.5% of the respondents correctly said that there was none as shown in Table 2

Table 2: *Number of health care professionals with specialized skills*

Specialized	Frequency	Valid Percent
None	15	18.5
1-4	49	60.5
More than 5	17	21.0
Total	81	100.0

Availability of other supportive systems to breast cancer pain management

About 56% of the respondents stated that referrals to healthcare professionals with specialized skills was not timely, 45.6% of the respondents stated that the health facility had put in place an interdisciplinary team for cancer pain management, and 61.2% of the respondents stated that nurses who managed pain in breast cancer patients received ongoing education, supervision, and support as shown in Table 3.

Table 3*: Health facility support systems*

	Yes		No		
Statement	**Frequency**	**Percent**	**Frequency**	**Percent**	**Total**
Referrals to healthcare professionals with specialized skills on cancer-related pain management are timely.	40	44.0	51	56.0	**91**
The facility has put in place an interdisciplinary team for cancer-related pain management.	41	45.6	49	54.4	**90**
Nurses who treat pain in breast cancer and other cancers receive ongoing education, supervision, and support.	52	61.2	33	38.8	**85**

Availability of guidelines to manage existential pain

On availability of facility guidelines to manage existential pain presented to them as a *feeling of lack of purpose and hopelessness* in breast cancer patients **(**n=96**),** all (100%) the respondents stated that there was no facility guideline currently, that they mostly encouraged and prayed for patients and availed strong analgesics to promote comfort.

Health facility barriers as reported by the departmental heads.

Further, to achieve the objective on health facility barriers, the researcher conducted two focused group discussions (FDGs) with the nurses' (departmental /unit heads and ward in charges) and other department heads who were directly involved with cancer pain management. The focused group discussion guide contained categories which needed responses. The thematic categories are described with 'voices' to create an in-depth understanding of the responses, the participants (PT) for the focused group discussions are identified by numbers to ensure anonymity, the theme and subtheme categories were; *Strict regulations on ordering and use of opioid analgesics, use of evidence based clinical decision making algorithms, availability and accessibility to opioid*

analgesics, **training, support and motivation for nurses involved in breast cancer pain management,** *regular periodic evaluation of cancer pain management processes by Interdisciplinary quality improvement teams and timely referrals to pain speciality, patients' satisfaction and outcomes.*

The following themes emerged from the analysis of the Focused group discussions;

Theme one: Strict regulations on ordering and use of opioid analgesics

The participants expressed concern that prescriptions for opioid analgesics were restricted to medical officers with strict processes involved before prescription, and any other prescriptions could not be honoured by the pharmacists, this immensely affected patients seeking pain management in primary health facilities with no Medical Officers, such facilities were not allowed to stock opioids either and only referred patients seeking pain management to Kisii County Teaching and Referral Hospital, this was regarded as costly. Participants recommended that the regulations be eased since they were impacting on the quality of care of patients, however this may not be a feasible recommendation because of the problem of opioid addiction and abuse and the scope of practice of other cadres.

The opioids were also kept and stored in line with the "Controlled Drugs Act" and estimation of opioid needs done based on previous consumption, the implications of basing need on previous consumption led to underestimating or overestimating the opioid needs.

"…*The opioids are under DDA (Dangerous drugs act, currently CDA), they must be recorded, they are available on duty room because there are restrictions on their use."(PT 04 FG1; PT 13 FG 2)*

"These drugs can be abused, if there a review; then all measures should be put in place to prevent abuse by staff and issue must be strictly against the palliative care number" (PT 08, 09 ,06 FG1; PT 11 FG2).

'Like now we are told to give reports on opioid use, they use the reports to estimate the needs, this may not be a true reflection of what we need, because as nurses we know that some deserving patients never get to get opioids" (PT 02 FG1; PT 12, 13 FG2).

Theme Two: Use of evidence based clinical decision making algorithms.

The participants pointed out that the commonly used algorithm was the World Health Organization Analgesic Ladder (WHO-AL) which was available in some units and nurses were allowed to use it within the limits allowed within the facility, it was also clear from the discussions that some nurses may not follow the WHO-AL in pain assessment and subsequent management because they viewed it as a sole responsibility of the Medical Officers, this led to inefficiencies in breast cancer pain management: There was no structured way such as a guideline to manage existential and emotional pain, spiritual pain was handled by the hospital chaplain. The departmental nurses said that they mostly prioritized management of physical pain in their departments, but further said that the hospital chaplain came around to pray for patients.

"General *cancer pain management is done using the WHO 3 step ladder, the algorithms are supposed to be placed in every department but you may find that some departments don't have it (PT 01, FG 1) "…The greatest challenge is that even if it is there, sometimes nurses belief that it is supposed to be used by doctors or clinical officers" (PT 05, FG1) "…to say the truth, nurses can use the ladder in all other ways, but when it comes to a prescription, we cannot honour that, maybe in future" (PT 06, FG1).*

'*Physical pain is what is handled here, we don't have any guideline to manage existential pain, and spiritual pain is managed by the hospital chaplain on the patient's individual request' (PT 01 FG1, PT 14 FG2)*

Theme three: Availability and accessibility to opioid analgesics:

The participants raised concerns about stock outs of opioid analgesics, one of the reasons was that opioid analgesics like morphine were not on the hospital's essential drug's list, thus the hospital purchased directly at a higher cost and could not subsidize the cost for the patients, patients could also not access the drugs using social Health Insurance like NHIF but via out of pocket payment, all patients who were prescribed morphine were also required to get a palliative care number to facilitate accessibility, this factors limited availability and accessibility to opioid analgesics by cancer patients:

"*The drugs are not always available, but when we have stock, we issue, the main problem is that Morphine is not on the hospital's essential drugs' list, we have to buy it directly, so it is expensive…(PT 06, FG 1). "Duty room has opioid drugs that can be availed to the patients (PT 03 FG 1), morphine syrup is available in the wards, initial dose can be given as the patient awaits to be given the palliative care number" (PT 16 FG 2), "DDA drugs cannot be in the essential drug's list (PT 18 FG 2) even chemists are not allowed to stock opioids" (PT 07 FG 1).*

Theme four: **Training, support and motivation for nurses involved in breast cancer pain management:**

Lack of adequate training specific to the type of cancer was cited as a factor that limited the nurses' ability to provide optimal cancer pain management, however there was an educational component on management of pain in general in the hospital's Continuous Medical Education (CME) programs which was not specific to breast cancer pain, from the discussions, nurses from primary health facilities were not included in the trainings since they were not actively involved in managing cancer pain, they were required to only refer patients to the County Teaching and Referral Hospital. The participants also voiced the challenges experienced by nurses who managed pain in cancer patients. Some felt that it was emotionally draining for nurses especially when they had patients experiencing high levels of pain with no relevant drugs for the level of pain, concerns of overworking due to understaffing were also raised. Some said that counselling supervision will be done monthly with the setup of the quality improvement team.

"…*Here we have CMEs on 'pain free hospital' weekly by Hospices and Palliative Care Alliance (KEPHCA) "(PT 05, FG 1), "Currently the training is ongoing every Thursday and Friday for 6weeks,' after this, we will have CME with specific nurses every 2nd Tuesday of the month" (PT 08, 09 FG1). "Nurses from primary health facilities are not included since they don't manage cancer pain" (PT 09, 05 FG1). "The patient will be referred, like Keumbu (Sub-county Health facility) there is a referral system, they don't manage cancer pain" (PT 08 FG 1; PT 17 FG2)*

"*There is a shortage of nurses, hence overworking really demotivates them, however they are mostly supported through counselling" (PT 10 FG1)*

"The quality improvement team will give suggestions on how nurses managing cancer pain will be supported, currently the hospital chaplain is usually available to support both nurses and patients" (PT 05 FG 1)

Theme five: Regular periodic evaluation of cancer pain management processes by Interdisciplinary quality improvement teams:

There was no clear regular periodic evaluation (audit) of cancer pain management processes, the processes were quite fragmented, and the audits were considered the responsibility of the palliative care nurse who did daily rounds to support cancer pain management. Participants said that the team had been set up and it was relatively new, all participants were in agreement that regular periodic evaluation will be done through the teams.

"*Yes, the team is in place and is composed of a medical officer, departmental nurses, nursing officer in charge of the Hospital, a nutritionist, physiotherapist...'(PT 05 FG 1) "…the hospital pharmacist is in the team and there is religious representation from the hospital chaplain"(PT 09,10 FG1).*

"*Currently there is no clear audit of cancer pain management processes here, the team is new and we are in the process of giving them the terms of reference" (PT 05, 07 FG1; 16 FG 2)*

Theme six: Timely referrals to pain speciality, patients' satisfaction and outcomes

The participants voiced concerns that there was no pain management consultant or oncologist in KCTRH at the time of the study. The patients with prolonged unrelieved pain were mainly referred to the national referral hospitals.

"*Patients with pain are usually given a referral note, a call is made to the referral facility" (PT 17 FG 2).*

"There *is no oncologists or pain management consultant currently, patients whom we feel need further evaluation are referred to MTRH or KNH" but we stabilize them first and some are referred via County Ambulance Service (PT 07 FG1)*

"*The hospital is in the process of setting up an oncology unit and automatically we will have the specialities coming on board" (PT 05 FG1).*

The participants voiced concerns that, primary health facilities were not at the time of the study allowed to manage cancer pain, and once they referred patients to Kisii County Teaching and Referral Hospital (KCTRH) some aspects of managing severe pain were not in place despite patients having high expectations that the services could over them relieve, this contributed to low satisfaction and poor outcomes with optimal pain relief according to the participants.

…"Patients' *expectations are quite high, we cannot give other forms of pain management like palliative chemotherapy because it is not available here and so far we have no donors to support the program' this negatively impacts on patient and service outcomes'(PT 08 FG 1; PT 16FG2).*

DISCUSSION

The findings from nurse respondents showed strict regulations to opioid use (25.5%), the results from the FDGs showed strict regulations with opioid analgesics being labelled as 'Controlled Drugs' and strictly issued to patients who were assigned a palliative care number, the hospital managers also reported that estimates for allocation were based on patients' previous utilization of opioids yet some patients deserving opioids never get to utilize them, hence underestimation was common, the findings on strict regulations to opioid access align with those described by Imeraj, Veseli, and Pirushi (2022) in a study done in Tirania where 43.7% of the nurses described delays in obtaining a prescription for opioid analgesics for their patients as barriers to administration of opioids to patients; similar findings were obtained in a study done in the west bank where 69.5 % of nurses reported strict regulations to opioid use with 56.4% reporting delays in getting a prescription of opioids for their patients as a barrier (Toba, Samara, and Zyoud., 2019).

The findings from this study that opioids have abuse potential and should be managed in line with the Controlled Drugs Act (CDA) and the strict ordering and estimation of opioid needs align with those obtained by a study done among patients by the American Cancer Society Cancer Action Network and the Patient Quality of Life Coalition which reported challenges of accessibility to opioid analgesics due to regulatory controls imposed on opioid drug abuse, (ACSCAN and PQLC, 2018), this further aligns with other researchers who have justified the need for control of opioids by reporting increasing illegal smuggling of opioids through Africa to Europe (Kurth et al, 2018), which further leads to more restrictions to accessibility of potent opioid analgesics, the findings further align with those of Namisango and colleagues who reported overly restrictive controlled laws, use of stigmatizing language in key documents "e.g dangerous drugs" inaccurate actual

opioid consumption estimation practices, critical shortage of prescribers; high out of pocket financial expenditures; and logistical, estimation and procurement challenges which leads to chronic stock outs of opioid analgesics (Namisango et al, 2018).

On the findings about fear of side effects (17.9%) of opioid analgesics, similar findings have been reported by various studies (Oliveiria, 2018; Charalambous et al, 2019).The findings that opioid analgesics were not always available and accessible as reported by nurse respondents (41.9%) and departmental heads align with those described in systematic review in Sub-Saharan African countries which pointed out limited accessibility to potent analgesic drugs (Odonkor, Kim and Erdek, 2017; Nchako et al, 2018) and those reported by Reid et al, (2018) in an Ethiopian study which reported very high costs of accessing opioid analgesics limiting accessibility by cancer patients; the findings also align with the World Health Organization estimates that 80% of the world population have insufficient access to appropriate opioid analgesics creating barriers to cancer pain relief for patients who require aggressive pain management (WHO, 2020). This finding on unavailability of opioid analgesics is a health system issue affecting most countries worldwide, which is further complicated by the opioid abuse pandemic, with the regulations imposed to curb misuse of this drugs, supporting policies have been put in place which have further complicated accessibility to opioids, this is evidenced by a report by the International Narcotic Board which stated that only 14.3% of morphine is used by low and middle-income countries while 85.7% of global consumption of morphine for pain management was utilized by countries in North America and Europe (International Narcotics Control Board, 2022).

The findings from this study that nurses did not optimally utilize validated clinical guidelines for assessment and treatment of cancer pain and that there was no guideline to guide management of existential pain (100%) aligns with the barriers reported by Deldar, Froutan and Ebadi (2018) which included time constraints due to shortage of nurses and lack of clear workplace policies on utilization of specific pain assessment tools leading to poor pain assessment and rating in cancer patients.

The findings from this study that 61.2% of the nurses had received cancer pain management training which was affirmed by the departmental heads who reported availability of weekly trainings by Kenya Hospices and Palliative Care Alliance (KEPHCA), is contrary to the findings reported by Charalambous and colleagues who reported inadequate training of healthcare workers (Deldar, Froutan and Ebadi, 2018; Charalambous et al, 2019), however the training described in this study is about the CMEs mainly among nurses and other health care workers, and some researchers have described failure of nurses to translate knowledge into practice further creating barriers to optimum pain relief among patients (Kwon, 2014).

The findings that referrals to healthcare professionals with specialized skills was not timely as reported by nurse respondents (56%), a lack of pain specialists and a functional interdisciplinary quality improvement team respectively (54.4%) as reported by the respondents align with those of Donati et al (2024) in their multicentre study in Italy which reported inadequate analgesic therapy and late referrals to pain speciality where 72% of patients referred late for palliative radiation therapy who additionally had ineffective analgesic therapy due to poor quality assurance procedures, the findings on unavailability of pain specialists further align with those reported in a systematic review on cancer pain management in Sub-Saharan Africa which reported limited funding, inadequate healthcare infrastructure, lack of trained health professionals as barriers to adequate pain relief among cancer patients (Odonkor, Kim and Erdek, 2017), similar findings have

also been described by Namisango and colleagues which included shortages of specific staff specialties for cancer pain management and low resource allocation to cancer pain management (Namisango et al, 2018; MOH, 2021).

CONCLUSIONS

The health facility barriers reported by the respondents and affirmed by the departmental heads caused inefficiencies in cancer pain management, limiting the ability of nurses to effectively provide pain management to cancer patients as per their scopes of practice. This included: Strict regulations and logistical challenges in accessibility to potent opioid analgesics, unavailability of opioid analgesics, lack of functional quality improvement teams, lack of pain specialists and non-utilization of validated clinical guidelines.

Recommendation

The researchers recommend that the Ministry of Health and the Kisii County Department of Health should facilitate policy changes to include revisions to the strict rules and regulations of prescribers and prescribing of opioid analgesics (while ensuring safety) to enable timely administration of opioid analgesics by nurses.

The department of health should put in place clear workplace policies on utilization of specific pain assessment tools and rating in cancer patients

The department should embrace effective models of opioid ordering and distribution to expand the scope of accessibility to morphine for patients with breast cancer, the county also has the potential to locally produce morphine and other opioids.

The Kisii County department of health should also consider setting up an oncology centre and employing specialists to include, a medical oncologist, breast surgeon, pain specialists and oncology nurses.

The department should also consider setting up a breast care centre within the oncology centre to manage the specific types of pain for patients with breast cancer which include; pain from lymphedema following surgery, pain at mastectomy side arising from surgery and/or radiation, shoulder pain, psychological pain and spiritual pain.

The Kisii Teaching and Referral Hospital should put in place measures to facilitate adequate training of nurses and other health professionals practicing in oncology using highly effective models, this is essential to provide effective pain management to improve the quality of care of patients with breast cancer.

Recommendation for further research

More studies are needed among other healthcare workers who are directly involved with breast cancer care and pain management.

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Conflict of interest

All authors have no conflict of interest

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SUB-THEME 5

Environmental, Technical and Policy Approaches in the Context of Climate Change Information and Adaptation for a Resilient Society

The consequences of climate change are on a global scale. Adaptation and resilience are the changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Therefore, this subtheme calls for abstracts, papers and posters that focus on: Restoration in the face of a changing climate; Innovation ecosystem for change mitigation and adaptation in a development context; Ecosystem based adaptation to address climate change among the rural, urban and peri-urban communities; Urban planning and development; Gender and environmental governance; and the Role of Youth in conservation and Green ecosystem infrastructure as a tool in management of peri-urban and other environments.

The Nature of Drought and Influence on Cereal Yields in Makueni County, Kenya

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Abstract

Increasing frequency and severity of drought is a major challenge to rain-fed cereal production and productivity hence food insecurity in Arid and Semi-Arid Lands (ASALs). Further, the location of Kenya along the equator, Indian Ocean coastline and widespread ASALs that cover 80% of the country, significantly increase vulnerability of the smallholder cereal farmers to frequent and severe droughts. The increase in severity and frequency of droughts have resulted in food supply gap and famine-related deaths in the past three decades despite drought management efforts by the Government of Kenya (GoK). The objective of this study was to establish the nature and effects of drought on cereal yields in Makueni County between 1990 and 2020. The study adopted Explanatory Sequential Mixed Methods Research Design. Rainfall data was obtained from Kenya Meteorological Department (KMD) for Makindu and Dwa Sisal Estate meteorological stations. Gridded rainfall data was also obtained from KMD for Kathonzweni and Salama meteorological stations. Standardized Precipitation Index (SPI) was used to establish the nature of drought while Pearson's *r* correlation analysis was conducted on rainfall and cereal yields. A survey on cereal farmers was also conducted to find out the cereal yield levels. The study established erratic, unpredictable and fluctuating rainfall patterns accompanied by 2 severe droughts, 1 moderate, 2 mild and 18 near-normal drought episodes. Frequent droughts in Makueni County resulted in low cereal yields where 43%, 42% and 60% of the cereal farmers produced between 1 to 10 bags of sorghum, finger millet and maize respectively. Information and data generated by the study is expected to result in better understanding of nature and effects of drought in Makueni County. This will enable achievement of the objectives of GoK and County Government of Makueni (CGoM) on improving adaptive capacity of the smallholder cereal farmers.

Key Words: ASALs, Drought

1. INTRODUCTION

Drought is a prolonged period of limited precipitation that is statistically below the seasonal or annual means recorded in a given region (Chivangulula *et al*., 2023; Tsige *et al.*, 2019). Drought indicators include variation in climatic conditions which results in a deficit in rainfall and high temperatures hence low moisture in soils and low water levels in hydrological systems. Drought contributes largely to soil degradation, loss of biodiversity and reduced productivity of ecosystems. Drought also leads to water stress in Arid and Semi-Arid Lands (ASALs) thereby influencing rain-fed cereal production, leading to poverty, and famine-related deaths.

An increase in frequency and severity of droughts was recorded in various parts of the world where 52 global mega-droughts were established between 1951 to 2016 (Spinoni *et al*., 2019); resulting in aridity and desertification. Africa experienced frequent and almost decadal droughts in 1910s, 1940s, 1960s, 1970s, 1980s, and 1990s (Masih *et al*., 2014). The frequent droughts have

contributed to the increase in aridity where approximately 16% of the land globally is ASAL (African Enterprise Challenge Fund [AECF] & NIRAS, 2021) while 43% of land in Africa is ASAL (Mabhuye *et al*., 2015).

Several drought episodes were experienced in the Horn of Africa (HoA) in 1980s, 2000s, and 2010s while Central parts of East Africa experienced severe drought in 2003 (Haile *et al*., 2019; Masih *et al*., 2014). These droughts significantly affected cereal yields despite the rapid annual increase in demand thereby making the continent food insecure.

According to Haile *et al*. (2019), over ten severe droughts were recorded in East Africa since 1970s whereby Kenya recorded droughts in 2010, 2011, and 2012. Further, increased drought severity and frequency significantly affected cereal yields hence food insecurity in Kenya (Mutua *et al*., 2016; Nyangena, 2020). Furthermore, Kenya experienced a reduced drought return period from five to three years during which the 1999-2000 La Niña droughts were indicated as the most severe in the last 50 years (Karanja, 2013).

According to Ghebrezgabher *et al*. (2016), Nyaoro *et al*. (2016), Ondiko and Karanja (2021) and Venton (2018), droughts occurred in all the decades since 1900 while severe droughts were experienced in Kenya in 1930s, 1940s, 1950s 1980s, 1990s and 2000s. The studies also indicated that the periodic droughts ranged from mild to severe; mostly affecting North-eastern, Coast, Nyanza, parts of North Rift Valley and Western and Eastern parts of the country. Numerous drought events were also identified as more severe where ASALs such as Makueni County were most affected. The increase in frequency and severity of droughts have heightened the unpredictability of the events hence increasing the vulnerability of the smallholder cereal farmers in the face of food insecurity in ASALs in Kenya.

Drought leads to significant fluctuations in cereal production. Besides, worrying projections between 10% to 20% maize yield reductions by 2050 have also been linked to frequent droughts (Omoyo *et al*., 2015). These significant fluctuations in cereal yields due to droughts are a major concern to the Government of Kenya (GoK), the County Government of Makueni (CGoM), smallholder cereal farmers and stakeholders in the agricultural sector in Makueni County which is a drought risk ASAL in Kenya.

The GoK and CGoM implemented the Kenya Cereal Enhancement Programme – Climate Resilient Agricultural Livelihood (KCEP-CRAL) which was effective from 2014 to 2022, in Makueni County through the Ministry of Agriculture (MA) (Food and Agriculture Organization of the United Nations [FAO], 2015; GoK, 2016). The main objectives of KCEP-CRAL were to contribute towards increasing productivity and profitability of key cereals - maize, sorghum, and millet, and associated pulses hence potentially improving national food security and smallholder income generation by supporting farmers in both medium- and high-potential cereal production areas in Kenya.

This article focused on drought-tolerant cereals such as sorghum, finger millet and dryland maize varieties. These cereals were chosen for this study due to their adaptability to varied Agro-Ecological Zones (AEZs) including ASALs such as Makueni County and because they are staple foods in the region. They were also chosen due to their nutritious nature and multipurpose uses including livestock feed and source of energy among other uses (Handschuch, 2014).

Sorghum and finger millet were also chosen for the study due to their autonomous adaptability to drought conditions, C_4 photosynthetic nature and high genetic variability (Belete, 2020; Borell *et al*., 2014; Crutchfield, 2017; Omoyo *et al*., 2015; Ranum *et al*., 2014; Tigchelaar *et al*., 2017). The cereals were also popular among communities in ASALs such as Makueni County. Furthermore, finger millet was also chosen for this study due to its disease-preventive health benefits (Saleh *et al*., 2013). Therefore, these cereals were regarded as having the potential of improving food security and nutrition in Makueni County.

2. Materials and Methods

2.1 Study Area

This study was conducted in Makueni County which is located 200 kilometres (km) Southeast of Nairobi city, Kenya. The County is located between latitudes 1^0 35' and 3^0 00'S and between longitudes 37^0 10' and 38^0 30'E (Figure 1). The County is bordered by Machakos County to the North, Kitui County to the Northeast and East, Kajiado County to the West and Southwest and Taita Taveta County to the South. Makueni County has a surface area of 8,177 square kilometres (km^2) (Kenya National Bureau of Statistics [KNBS], 2019). The County has six Sub-Counties namely: Mbooni, Kilome, Kaiti, Makueni, Kibwezi West, and Kibwezi East (KNBS, 2019). The sample study sites were Kibwezi West, Kibwezi East, Makueni and Kilome sub-Counties. Makueni County was purposively sampled for the study due to climatic and socio-economic factors.

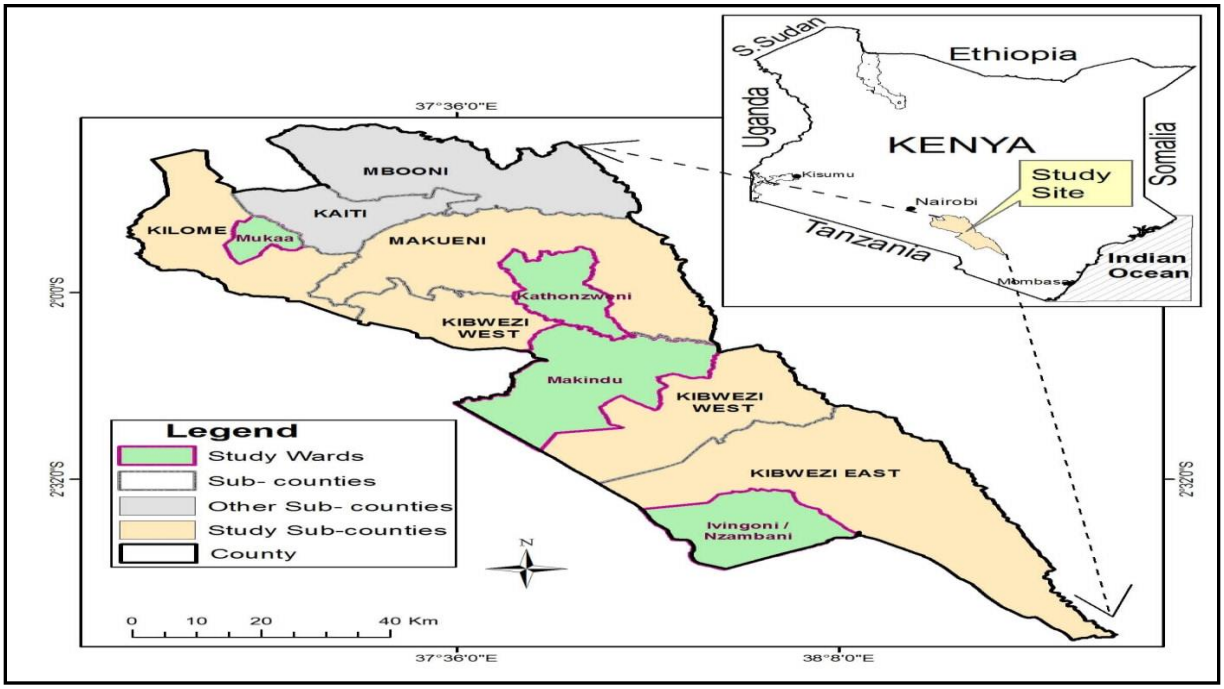

Figure 1: **Map of the Study Area Showing the Study Sites.**

Source: IEBC (2013).

2 Data Collection

This study collected daily rainfall data from meteorological stations and gridded rainfall data from Kenya Meteorological Department (KMD) to derive annual rainfall mean for 1990 to 2020. The data sets were collected from 4 meteorological stations distributed across Makueni County and recorded from 1990 to 2020. The study also used cereals (sorghum, finger millet and maize) data which were collected from MoA, Makueni County, for 1990 to 2020. In addition, a survey was used to collect data from cereal farming households on cereal yields and farm sizes in Makueni County.

2.3 Data Analysis

The datasets were processed and subjected to control checks for data quality and homogeneity tests. Missing values in both rainfall and cereals data were filled using Multiple Imputation (MI) method which is relevant for filling statistical gaps (Lloyd *et al*., 2013).

Annual rainfall means was analysed based on March 12-month SPI time series. SPI was used to establish meteorological droughts for the time scale identified for the study (Diani *et al*., 2019). The annual rainfall data sample Y: 1=1, 2, 3,… n was assumed to be independent and distributed identically. The independent observations were used as the source of data at specified data points. Further, SPI values were considered to be varying from -2.0 to 2.0. Drought episodes were recorded when SPI values turned negative while the episode ended when the SPI became positive (McKee *et al*., 1993). SPI has an index which is used for drought categorization (Table 1). The equation for SPI is indicated in Equation 1.

$$SPI = \frac{X - \bar{X}}{\sigma} \quad \text{..... (Equation 1)}$$

Where: X - Precipitation
$\bar{x}$ - Mean Precipitation
σ – Standard Deviation

Annual rainfall mean was correlated with annual cereal yields at 5% levels of significance, based on Statistical Package for Social Sciences (SPSS) version 22. Karl Pearson's Coefficient of Correlation (PCC), a bivariate correlation based on the coefficient of determination, Pearson's *r* was used for the analysis. The correlation analysis examined the effect of drought on cereal yields whereby the strength of the association and direction of the relationship was identified. PCC varies from -1 to 1. A PCC>0 is an indication of the existence of a positive correlation between the two variables. On the other hand, a PCC<0 is an indication of the existence of a negative correlation between the two variables, while PCC=0 indicates the non-existence of a correlation between the two variables.

Table 1**: Drought Characteristics Using Standardized Precipitation Index**

SPI Range Value	Drought Category
>2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near-normal
-1.00 to -1.49	Mild drought
-1.50 to -1.99	Severe drought
<-2.00	Extreme drought

Source*:* McKee *et al*. (1993)

3. Results and Discussion

3.1 Rainfall Trends in Makueni County

Results of the analysis of the rainfall trend revealed fluctuations in amount of rainfall from 1990 to 2000 (Figure 2). There was a significantly high amount of rainfall in 1998 due to El Niño event. In addition, there were fluctuations in amount of rainfall received between 2008 and 2017. Rainfall amounts also indicate an increasing trend from 2018 to 2019 then a declining trend in 2020.

The results of this study are in concurrence with those of a study done in China by Liu *et al.* (2020) which established fluctuations in rainfall trends whereby a decreasing trend was identified in Northern China from mid-1970s. The declining trend in rainfall was associated with increasing temperatures in the region and the weakening trend of East African Summer Monsoon (EASM).

The results of this study are also in agreement with those of a study done in Southern Ethiopia by Shibru *et al.* (2023) which established a high variability in rainfall (20%-35%) in Southern Ethiopia as compared to the variability in East Africa which was indicated as ranging between 15% to 25%. The high rainfall variability in both regions is an indication of increased drought risks. The study also revealed that high variability in rainfalls in Southern Ethiopia were exacerbated by rising temperatures experienced in the HoA. Further, the results of this study are in concurrence with those of a study done in Sudan by Yagoub *et al*. (2017) which established an association between increasing drought frequency with declining rainfall from 1961 to 2013.

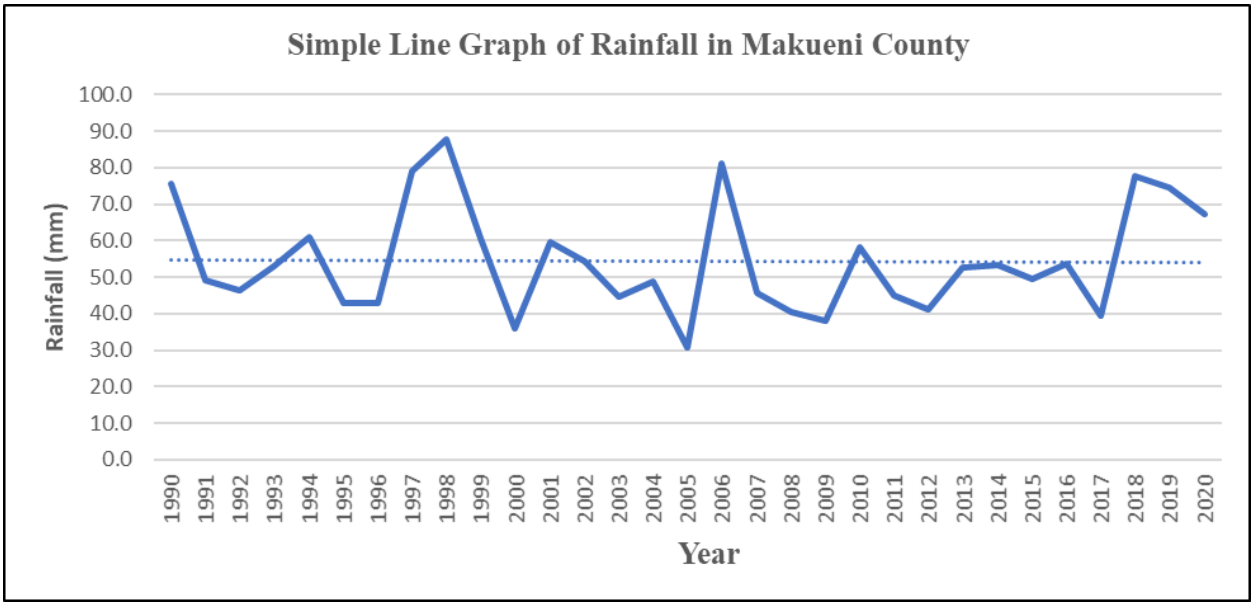

Figure 2: **Rainfall Trend in Makueni County**

Source**: Field Data (2023)**

3.2 Drought Characteristics in Makueni County

This study established 18 episodes of near-normal droughts while 2 mild droughts and 1 episode of moderate drought were experienced in Makueni County between 1990 and 2020 (Figure 3). Severe droughts occurred between 2004 and 2005. Further, near-normal droughts occurred annually from 1992 to 1996, 1999 to 2002, 2007 to 2008, and 2011 to 2016. The near annual drought conditions were also exacerbated in the study area by recurrence of mild droughts in 2000, 2009 and 2017. Further, mild droughts occurred in 2000, 2009 and 2017. Furthermore, a severe multi-year drought occurred in 2004/2005. These drought conditions are an indication of erratic, unpredictable and fluctuating rainfall which significantly impacted cereal production and yields in Makueni County.

The results of this study mirror those of a study conducted by Chivangulula *et al*. (2023) which established that droughts accounted for 6% of total disasters globally where 7% of all economic loses were linked to the phenomenon. The study also established a high frequency of droughts in South Africa that were indicated by a three to five-year return period between 1980 to 2007. Wang *et al.* (2023) also established that drought events were fewer in Southwest China before 1930s. However, the frequency of drought events increased in the region after 1930 whereby severe droughts were experienced between 1936 to 1937 in the region. In addition, South Western China experienced more severe droughts in 1962, 1963, 1967, 1987, 2009 and 2010. The severity of the 2009 and 2010 droughts had not been felt in the 120 years under study. Ayugi *et al*. (2022) also revealed that frequent and prolonged severe droughts were common in North Africa which cause significant socioeconomic impacts and change in land use in the region where 70% of the land surface area is a desert.

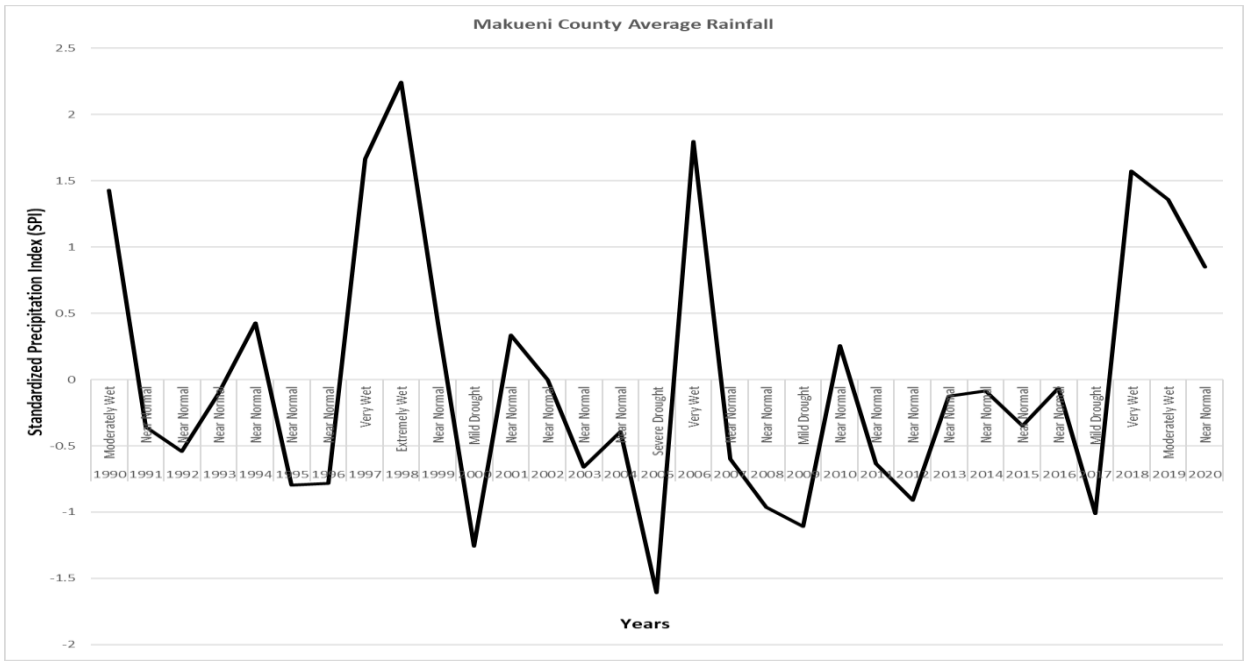

Figure 3: **Drought Trends in Makueni County**

Source: Field Data (2023)

3.3 Cereal Production Trends

There were significant fluctuations in sorghum, finger millet and maize yields in Makueni County between 1990 and 2020 (Figure 4). However, there was a significant increase in millet yields between 2008 and 2011 followed by a decline in yields between 2011 and 2012. On the other hand, sorghum and maize yields fluctuated over a similar period. Sorghum, finger millet and maize yields were consistently low between 2012 and 2014. Thereafter, a significant increase in maize yields was recorded from 2014 to 2016 which was followed by yield fluctuations up-to 2019. An increase in maize yield was also recorded from 2018 to 2019 followed by a sharp decline in 2020. On the other hand, a consistently gradual increase in sorghum and finger millet yields was recorded between 2016 and 2020.

The results of this study corroborate those of as study conducted by Odeph *et al. (2020*) which revealed that approximately 30.73 MMT of finger millet is produced annually globally where fluctuation in acreage was recorded. The results of this study are also in agreement with those of as study conducted in Ethiopia by Belete (2020) which established low maize yields at 3.06 tonnes per hectare (tha^{-1}) despite a high potential between 7.0 to 12.0 tha^{-1} annually.

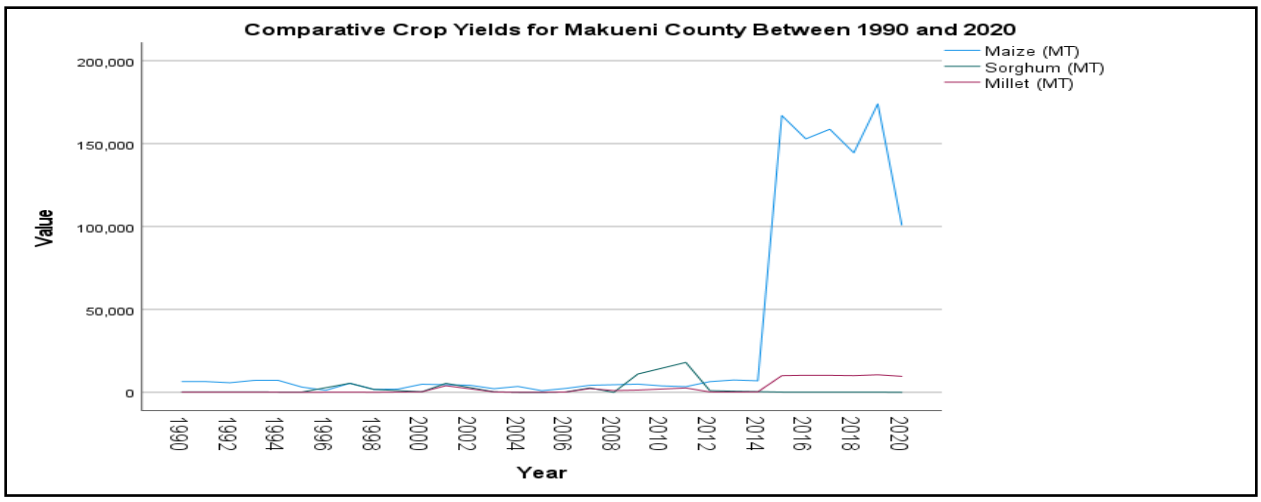

Figure 4: **Cereal Yields Trend in Makueni County**

Source: Field Data (2023)

3.5 Correlation of Drought and Cereal Yields

The results of the correlation analysis of rainfall and cereal yields show that there was a significant, strong, positive correlation between rainfall and sorghum yields in Makueni County, $r(29) = .699$, $p<0.01$ (Table 2). The existence of a strong positive correlation between rainfall and sorghum yields is an indication that increase in amount of rainfall leads to an increase in sorghum yields in Makueni County and vice versa.

The results of this study show that there was a significant, weak, positive correlation between rainfall and finger millet yields in Makueni County, $r(29) = .359$, $p<0.01$ (Table 2). The weak positive correlation between rainfall and finger millet yields shows that increase in amount of rainfall leads to an increase in finger millet yields in Makueni County. On the other hand, a reduction in amount of rainfall leads to decrease in finger millet yields in Makueni County.

The results of this study show that there was a significant, weak, positive correlation between rainfall and maize yields in Makueni County, $r(29) = .346$, $p<0.01$ (Table 2). The existence of a weak positive correlation between rainfall and maize yields shows that increase in amount of rainfall leads to an increase in maize yields in Makueni County while a deficit in amounts of rainfall hence drought conditions significantly affects maize yields.

These results of this study corroborate those of a study which was conducted in South Africa by Chivangulula *et al*. (2023) which established that droughts significantly impacted socioeconomic activities between 1991 to 1992. The study also established that up-to 20 million people were affected by famine in the country.

Table 2: Correlation between Rainfall and Cereal Yields

Correlations

		Makueni County Averaged Rainfall (mm)	Maize (MT)	Sorghum (MT)
Makueni County Averaged Rainfall (mm)	Pearson Correlation	1	.175	-.072
	Sig. (2-tailed)		.346	.699
	N	31	31	31
Maize (MT)	Pearson Correlation	.175	1	-.244
	Sig. (2-tailed)	.346		.186
	N	31	31	31
Sorghum (MT)	Pearson Correlation	-.072	-.244	1
	Sig. (2-tailed)	.699	.186	
	N	31	31	31
Millet (MT)	Pearson Correlation	.171	.958**	-.089
	Sig. (2-tailed)	.359	.000	.634
	N	31	31	31

Source: Field Data (2023)

3.5 Effect of Drought on Cereal Yields

The high frequency of droughts in Makueni County indicated by 18 near-normal drought episodes between 1990 to 2020 (Figure 2); significantly affected cereal production and yields in the region. The effect of drought on cereal yields in Makueni County is shown by low cereal yields whereby majority, 43% of the cereal farmers produced between 1 to 10 bags of sorghum (Table 3). The effect of drought on sorghum yields is also shown by the small farm sizes used for cereal production whereby majority, 32.9% of the smallholder cereal farmers produced sorghum on 0.1 to 0.5 hectares of land (Table 5). The use of small hectarage for cereal production in Makueni County is a potentially a result of the effects of droughts, hence a cause of low cereal yields.

This study also revealed that drought negatively affected the production and yields of finger millet in Makueni County. Majority, 42% of the finger millet farmers in the study area produced between 1 to 10 bags of the cereal, whereas only 5% of the farmers produced above 11 bags of the cereal in Makueni County (Table 3). The low annual finger millet yields were associated with frequent drought episodes in Makueni County. The low cereal yields are also corroborated by a study conducted in India by Patel *et al*. (2022) which established low finger millet (Ragi) yields in the rural regions of Chhattisgarh in India with yields at 0.253 tha^{-1}. In addition, 30.2% of the smallholder cereal farmers produced finger millet on small farms ranging from 0.1 to 0.5 hectares of land in Makueni County (Table 5).

Even though majority, 60% of the cereal farmers produced 1 to 10 bags of maize annually in Makueni County (Table 3), the low yields are a key challenge to food security in the region. The study also revealed that only 29% of the cereal farmers produced above 11 bags of maize annually;

signifying depressed maize yields under frequent drought conditions. The frequent near-normal drought episodes potentially resulted in small hectarage under maize where 24.4% of the smallholder cereal farmers produced the cereal on only 0.1 to 0.5 hectares of land in Makueni County (Table 5). The small farm sizes used for cereal production are a pointer to the significant negative effect of drought on cereal production and yields in the study area.

The results of this study concur with the results of a study conducted in South Africa by Chivangulula *et al*. (2023) which established that droughts significantly affect crop production and yields in the region where food insecurity and malnutrition were recorded. Further, Ayugi *et al*. (2022) established widespread drought episodes which affected the rainfed agricultural activities of majority of the population hence food security in East Africa.

Table 3: Annual Cereal Production in Makueni County

Type of Cereal	**Production (90 kg bags)**							
	0-10	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**>70**
Sorghum	43%	3%	1%	0%	0%	0%	0%	1%
Finger Millet	42%	4%	1%	0%	0%	0%	0%	0%
Maize	60%	16%	5%	4%	1%	1%	1%	1%

Source: Field Data (2023)

Table 4: Effect of Drought on Cereal Yields

Effect of the drought on cereal yields	**No. of Respondents**	**%**
Reduction in yields	193	91.1
No change	10	4.9
Increase in yields	9	4.0
Total	**212**	**100.0**

Source: Field Data (2023)

Table 5: **Farm Size in Hectares in Makueni County**

	Sorghum		Finger Millet		Maize	
	No. of Farmers	Percent	No. of Farmers	Percent	No. of Farmers	Percent
No response	103	48.4	115	54.2	15	7.1
0.0-0.5	70	32.9	64	30.2	52	24.4
0.6-1.0	14	6.7	12	5.8	33	15.6
1.1-2.0	14	6.7	13	6.2	49	23.1
2.1-3.0	7	3.6	6	2.7	38	17.8
>3.1	4	1.8	2	0.9	25	12.0
Total	212	100.0	212	100.0	212	100.0

Source: Field Data (2023)

5. Conclusions

The occurrence of 18 near-normal drought episodes in Makueni County between 1990 and 2020 is an indication of frequent droughts. These frequent droughts were also indicated by cases of multi-year droughts. Occurrence of severe droughts in Makueni County also reflected the significant effects of the events on cereal production in the County. Recurrence of near-normal, mild and severe droughts in Makueni County have also resulted in increased vulnerability of smallholder farmers. The frequent droughts have also resulted in adverse cereal production conditions which have significantly affected cereal yields and food security in the region. The significant and positive correlation between rainfall and sorghum, finger millet and maize yields also score the role of drought in influencing food security and nutrition in Makueni County. Even though majority of the smallholder farmers produce less than ten bags of cereals annually as a result of the adverse production conditions caused by frequent droughts, drought adaptations can potentially improve cereal production and food security in Makueni County.

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